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Agricultural Experiment Station

University of Kentucky

A STUDY OF CLOVER FAILURE IN KENTUCKY

BULLETIN NO. 269

(Research Bulletin)

Lexington, Ky.

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A Study of Clover Failure in Kentucky

E. N. FERGUS and W. D. VALLEAU

CLOVER SICKNESS IN EUROPE

Difficulties attending the culture of red clover (*Trifolium pratense L.*) have long been recognized. Worlidge (48), an English author, wrote, in 1669: ''Poor lands are not fit for clover unless burnt or denshired, as we shall hereafter direct, or limed, marled, or otherwise manured, and then it will bring forth good clover.'' In this country Jared Eliot (12) wrote, in 1747, that ''our worn out land is poor and will not produce clover.'' He also speaks of clover failures.

In 1804 Arthur Young (49) described difficulties which were being experienced in many parts of England, stating that clover was ''extremely apt to fail in districts where it has been long a common article of cultivation. The land, to use the farmer's term, becomes *sick* of it. After wheat harvest he has a fine plant, but by March or April half or perhaps more of it is dead.'' He stated that allowing eight years instead of four between successive clover crops had been found a satisfactory remedy. He also noted that one farmer on ''clover sick'' land found that by deep plowing and heavy manuring he could grow clover every third year. Miller (26), however, noted that while manure would increase the crop, it would not prolong its stay.

In 1834 a Scottish writer (34) mentioned the falling off of crop yields on their lighter soils. In regard to clover he stated that in his father's day ''three cuttings of clover were not uncommon,'' while in his day a good second cutting was rarely obtained.

By 1849 clover sickness had become so serious in parts of England that their Norfolk rotation was apparently being

changed to permit longer intervals between the clover crops (33). It appears that the red clover disappeared during the first winter, usually, regardless of soil or manurial treatment. One writer (41) of this period, however, distinguished definitely between two types of clover sickness. In addition to the one described by Young, which caused a disappearance of the clover between October and April of the first winter, which he describes as true clover sickness, he recognized another which caused the crop to disappear during the first summer. He further noted that soil productivity was a factor, the difficulty being more serious on the poorer, non-calcareous soils.

Clover sickness was not confined to England and Scotland, however, during the first part of the 19th century. One writer already quoted (33) says that in Flanders, whence red clover was originally brought into England, the "land has been longer tired with its repetition" than it has in England. Part of the difficulty, however, was due to what must have been broomrape (*Orobanche* sp.). Handley (19), after a visit to Germany, reported that in the neighborhood of Dresden, where the land was clover sick, it would not do well on the same land every fourth year.

The Rothamstead Experiment Station interested itself in the clover problem in 1849, studying its relation to mineral plant food in the soil. In 1860, Lawes and Gilbert (23), reviewing these experiments, came to the following conclusion: "When land is clover sick none of the ordinary manures or fertilizers can be relied upon to secure a crop" and "the only means of securing a good crop of red clover is to allow some years to elapse before repeating the crop upon the same land." It appears, however, that the use of phosphates and potash reduced the severity of the sickness. The writers also mentioned that a small area in a kitchen garden, not far from the clover-sick field, was seeded to red clover during the spring of 1854. This plot yielded fourteen cuttings without soil treatments and without resowing, yielding at the rate, on the average, of nearly 4½ tons per acre, per year. With the application of mineral fertilizers, the yields

were increased to an average of more than $5\frac{1}{2}$ tons per acre. Their general conclusion from all of their experiments was that the sickness was "connected with the conditions of the soil in relation to the plant."

Thus, prior to 1870, clover sickness was apparently generally considered a soils problem thruout Europe, some believing the difficulty due to the lack of some essential mineral or minerals, others attributing it to the presence in the soil of toxic material excreted by the plant. A few had other theories, but all were based on the assumption that something was wrong with the soil.

About this period, however, evidence began to accumulate which directed attention to other possible causes of clover sickness. Hoffman, according to Eriksson (13), in 1863, reported the fungus *Peziza ciborioides Fr.* to be responsible for a part of clover sickness in Germany. Eriksson, however, found the organism to be a new species and named it *Sclerotinia trifoliorum*. A paper by Rehm (35), in 1872, in which *S. trifoliorum* Erik. was shown positively to be responsible for clover failures, apparently was responsible for a general extension in the scope of clover failure studies.

According to Voelcker (45), Miss Ormerod, in 1877, reported a nematode (*Tylenchus* sp.) as a cause of clover sickness in England. Smith (38) a few years later recognized the nematode as a cause of clover troubles but stated that this type of trouble could be distinguished from the true clover sickness. He believed that there might be several causes of clover sickness. Carruthers (8, 9), in 1897 and 1898, named the two fungi *Peronospora trifolii* and *S. trifoliorum* Erik., as causes of clover sickness, with the latter as the more important. He stated that this organism had long been known in England. Gussow (18), in 1903, showed *S. trifoliorum* Erik. to be a cause of clover sickness in England.

A Russian writer (3) put forth the theory, in 1902, that clover sickness results from a continual struggle between the clover plant and the root nodule bacteria. He believed that too many bacteria in the soil, many of which failed to become trans-

formed into bacteroids, caused the clover sickness. Other Russian investigators (44) stated that clover sickness existed in central Russia and that it was not exclusively due to the lack of plant food.

Three other Russian reports were published in 1905 and 1907 (7, 15, 22) supporting the view that clover sickness was intimately connected with, if not actually caused by, malnutrition of the plants. It appeared that a lack of available phosphoric acid was most frequently the cause. Budinov (7), however, added that the beneficial effect of applying phosphatic and potash fertilizers to clover-sick land was due not only to the favorable action of the fertilizers on the clover plant, but also to their action in increasing the virulence of *Bacillus radicicola*.

Amos (1), discussing this problem before the Farmers' Club of London, in 1916, reviewed the various theories as to the cause of clover sickness and then presented evidence to show that either the eelworm (*Tylenchus devastatrix*) or the fungus *S. trifoliorum* Erik. was the cause of certain clover failures which he had observed.

In the discussion which followed Mr. Amos' presentation, Mr. A. D. Hall expressed his belief that while Sclerotinia might be the main cause of the death of clover, he felt that there might possibly be some other causal factor which was not yet understood. He noted that plants varied in susceptibility under different conditions. Dr. H. B. Hutchinson expressed a similar view specifying that the favorable or unfavorable nutrition of the plant affected its resistance or susceptibility. Dr. J. A. Voelcker stated: "Because one finds a particular thing present it does not warrant one saying that this is the cause of a certain disease." He expressed himself as by no means satisfied that either the eelworm or Sclerotinia was the cause of clover sickness. He too, seemed inclined to believe that something was contributing to the unhealthy condition of the plant which permitted these so-called causes to operate.

In 1918, Amos (2) presented another paper in which he expressed his belief that the eelworm was more important than Sclerotinia as a cause of clover sickness, at least in certain areas.

Dr. E. J. Russell, in a letter to the senior author, states that he believes the chief causes of clover "sickness" in England to be "1, Sclerotinia; 2, nematodes; 3, exhaustion of calcium carbonate from the soil, whereby the soil reaction gradually changes from neutral to acid." He goes on to say that it is quite possible a more extended investigation may reveal other causes and that he does not wish to suggest these causes as the only factors contributing to the sickness.

CLOVER SICKNESS IN AMERICA

As has previously been stated, Jared Eliot, in 1747, mentioned difficulties in growing red clover on worn-out lands. Just when the term clover "sickness" was first applied to difficulties in growing clover in this country is not known. Certainly it was used early in the 19th century. According to Pieters (29) it was reported from Pennsylvania in 1820 and Ohio in 1866. A report from New Jersey (27), in 1885, stated that there was much complaint that clover was not as successful as formerly. It suggested the exhaustion of mineral plant foods from the soil as the cause. Reports from North Carolina in the early nineties suggested microorganisms as the cause of clover sickness but expressed doubt whether the disease was present in this country in more than limited areas, if at all (24, 25).

Bain and Essary (5), in 1905, showed that anthracnose caused by *Colletotrichum trifolii* B and E, was responsible for some of the clover failures in Tennessee.

In 1908 the Ohio Experiment Station (28) reported that clover failures were becoming increasingly frequent in eastern and southern Ohio, giving two principal causes: (1) exhaustion of lime from the soils; (2) a fungus disease of the plant.

Sclerotinia trifoliorum Erik. was given as a cause of clover sickness in Kentucky, in 1915 (17). Later reports from other observers indicated its presence in Canada, New York, New Jersey, Virginia, Indiana, Oregon, South Carolina and other sections of the United States (16, 17, 18, 46). It is apparent, however, from these statements that this organism is not gener-

ally of great importance in causing the losses of red clover crops on this continent.

Pieters has recently stated (29) that clover failure presents a serious problem in northeastern United States and that while it is not yet serious in such states as Wisconsin, Minnesota and Iowa, "the complaint is moving west just as it has done for more than 100 years." He has shown that as a result of these increasingly frequent clover failures the clover acreage has fallen alarmingly since 1900, tho it has been increasing somewhat of late years.

It appears, therefore from the above review, that the term "clover sickness" has been used to designate any condition which was causing clover failure. It has more often been associated with the more extreme forms of failure but has always been a rather indefinite term. Pieters (30) has aptly summarized the present understanding of the term when he says: "The soil does not become 'sick of clover' but the clover itself may become sick, as indeed it does when attacked by specific diseases or when the soil conditions are not suited to its growth. It is now recognized that there is nothing mysterious about clover failure. Clover fails either because the soil is unsuited to its development, because it is attacked by a fungus or by an insect or a nematode, or because of the use of seed of strains not adapted to the climatic conditions prevailing in the United States."

While it is true that most clover failures can be traced to certain apparent causes, yet the fact remains that these causes are not well understood. Every experiment station in the central and eastern states, thru its soil experiment fields, has demonstrated that good yields of red clover can be grown with proper soil treatment, but the underlying reasons have not been explained. The fact that red clover can be grown on any soils in the central and eastern states after they have received certain soil treatment, simply serves to emphasize the necessity of a thoro study of the ecology of the crop. To one group of investigators the problem has appeared to be primarily a soil or nutritional problem, while to another it has seemed mainly pathological.

CLOVER SICKNESS IN KENTUCKY

The situation regarding clover culture in Kentucky is not essentially different from that in other states of eastern United States. While on a few soil areas, principally the Bluegrass region, clover growing is reasonably certain, on a majority of the soils more or less difficulty is experienced with the crop. Inasmuch as these difficulties have arisen gradually, the farmers can not assign the first clover failures to any definite date but all are agreed that the crop was more easily grown when the state was much younger agriculturally. There is evidence, however, that the soils of the Bluegrass region are, to a less degree, experiencing the same difficulties which have become all too common in other parts of the state.

In order to secure some accurate data on clover failures, especially with regard to the actual time at which the crop fails, the authors made a preliminary survey in the hope that some suggestion could be obtained as to critical periods in the life of the clover plant. It was found that many plants were dying during the hot summer weather immediately following harvest. Examinations of the plants at that time revealed roots which were so severely rotted that only the upper portions of the tap roots and larger laterals remained as evidence of former well-developt root systems.

Consequently, a study was projected which should determine just when the mortality of established stands occurred and whether there really existed any physical manifestations in the plant as a whole accompanying death and what was the significance of any such correlative conditions as might be found.

PLAN OF THIS STUDY

As was stated in a preliminary report on this study (14), the field work was undertaken on three soil experiment fields in this state: (1) the Experiment Station farm at Lexington; (2) the Campbellsville experiment field in Taylor County; and (3) the Berea experiment field in southern Madison County. The Lexington field is located upon a highly productive soil which rarely experiences clover failure. The Campbellsville field rep-

resents a soil of medium productivity upon which clover fails frequently and rarely produces well unless the soil has been limed or fertilized with phosphorus. The Berea field represents soil of very low productivity which will not produce clover successfully without lime, phosphorus and potash and frequently will not do so with these treatments.

The physical nature of the soils on which these three fields lie varies widely. The soil underlying the Lexington field is a residual soil resting upon the Trenton limestone formation. The surface soil is a reddish-brown silt loam, grading off imperceptibly into the subsoil. At about 30 inches this becomes distinctly yellowish in color and of a heavy clay texture.

The Campbellsville soil consists of residual material derived from rocks of the upper Waverly formation which were largely calcareous in nature. The surface soil is a brownish silt loam to a depth of 7 inches. The subsoil, beginning at 7 inches and extending to about 27 inches, is a somewhat mottled yellowish clay to clay loam. The subsoil under the field is not entirely uniform in character, due to the fact that a number of stumps had been removed in recent years. As a result, in places the subsoil shows areas containing considerable amounts of organic matter.

The Berea soil lies in the Devonian horizon, having been derived from the Devonian, Waverly and higher formations.* The surface soil to a depth of 6 inches is a grayish loam. At 6 inches it begins to change gradually, becoming at 15 inches a mottled yellow and gray silt loam of poor natural drainage. The field has been tile drained.

For a general statement on the soils which these fields represent, the reader is referred to Bulletin 193 of the Kentucky Station, "The soils of Kentucky" (4).

The project was divided into two lines of investigation; first, the determination of the actual mortality of clover plants from season to season on plots of varying productivity; second, an attempt to ascertain whether any visible correlation exists

*The authors are indebted to Mr. S. C. Jones for the statements as to the derivation of the particular soils underlying the Campbellsville and Berea fields.

between the condition of the roots of the clover and the rates of mortality.

Certain plots from each of the soil fields were selected for study, on the basis of past crop yields. The plots chosen, their treatments, and yields are shown in Table I.

TABLE I.

Crop yields on certain plots of three soil experiment fields which were chosen for clover mortality studies.

The Lexington Soil Experiment Field

Plot Numbers* and Treatments	Clover Hay lbs. per A. Ave. 9 yrs.	Corn Bus. per A. Ave. 13 yrs.	Wheat Bus. per A. Ave. 11 yrs.	Soybeans Bus. per A. Ave. 12 yrs.
9. (RLPK)	4425	53.7	26.7	21.0
10. (O)	4116	54.5	23.7	18.9

The Campbellsville Soil Experiment Field

Plot Numbers* and Treatments	Clover Hay lbs. per A. Ave. 3 yrs.	Corn Bus. per A. Ave. 4 yrs.	Wheat Bus. per A. Ave. 3 yrs.
2. (O)	710**	20.8	3.1
3. (L)	785**	26.6	4.0
Checks (O)***	948	25.2	4.1
5. (AP)	2112	41.5	7.5
11. (LAP)	2863	46.3	10.0
14. (RP	2662	36.2	5.6
15. (LRP)	1670	34.6	5.9

The Berea Soil Experiment Field

Plot Numbers* and Treatments	Clover Hay lbs. per A. Ave. 5 yrs.	Corn Bus. per A. Ave. 11 yrs.	Soybean Hay lbs. per A. Ave. 10 yrs.
1. (O)	106	16.5	1630
2. (LM)	698	40.8	3549
8. (M)	336	27.1	2906
9. (LMAPK)	1932	44.0	4587

*Plot numbers: In this and all following tables, unless the hundreds digit is included in the plot number, the numerical plot designation refers to a plot treatment which is identical on all series of the experiment field and the data given represent the average for that treatment on all series for the period designated.

**Average of two years.

***The check plots at Campbellsville sometimes receive a cowpea green manure crop between the clover and corn crops.

Plot Treatments:

O = no treatment, crop residues removed.
M = manure.
L = ground limestone.
AP = acid phosphate.
RP = rock phosphate.
K = potash.
R = crop residues.

Amounts used:

LEXINGTON SOIL EXPERIMENT FIELD

Residues:
Returned on plot 9 since 1916 (inclusive): cornstalks, soybean straw and wheat straw. Second crop clover turned under on both plots.

Limestone:
4 tons per acre per rotation, 1911-1915.
2 tons per acre per rotation, 1916-1918.
1 ton per acre per rotation, 1919-1924.

Acid phosphate:
800 pounds per acre per rotation, 1911-12.
400 pounds per acre per rotation, 1912-24.

Potash:
500 pounds sulfate of potash per acre per rotation, 1911-1915.
400 pounds per acre per rotation, 1916-1922.
200 pounds per acre per rotation, 1922-1924.

CAMPBELLSVILLE SOIL EXPERIMENT FIELD

Limestone 2 tons per acre per rotation.
Acid phosphate 900 pounds per acre per rotation.
Rock phosphate 1200 pounds per acre per rotation.

BEREA SOIL EXPERIMENT FIELD

Manure 1917-1921 at rate of 6 tons per acre per rotation; 1922 to present time, a weight equal to that of produce removed.
Limestone 2 tons per acre per rotation, 1913-1920.

Acid phosphate:
800 lbs. per acre per rotation, 1913-1920.
400 lbs. per acre per rotation, 1921-1924.

Potash—sulfate or equivalent:
400 lbs. per acre per rotation, 1913-1915.
200 lbs. per acre since then.

The hydrogen ion concentration of the soil of the different plots listed in Table I were determined electrometrically by Prof. P. E. Karraker, of the Agronomy Department, on composite fresh samples of soil which were collected about August 1, 1924. The pH values found are given in Table II.

TABLE II.

Hydrogen ion concentration of the soils of certain plots of three soil experiment fields in Kentucky.

Lexington Soil Experiment Field

Plot No. and Treatment	pH Values at Soil Depths of		
	0–7 in.	8 in.–15 in.	24 in.–36 in.
309 (RLPK)	6.52	5.89	6.03
310 (O)	5.18	5.23	5.98

Campbellsville Soil Experiment Field

Plot No. and Treatment	pH Values at Soil Depths of		
	0–7 in.	8 in.–15 in.	18 in.–24 in.
102 (O)	5.30	5.36	
103 (L)	6.80	5.60	
705 (AP)	5.36	5.33	
710 (O)	5.75	5.32	4.79
711 (LAP)	7.19	5.33	4.94
714 (RP)	5.65	4.99	
715 (LRP)	6.87	5.35	

Berea Soil Experiment Field

Plot No. and Treatment	pH Values at Soil Depths of		
	0–6 in.	7 in.–14 in.	15 in.–21 in.
101 (O)	4.91	4.69	4.61
102 (LM)	6.75	4.93	
108 (M)	4.86	4.73	
109 (LMAPK)	6.67	4.93	4.64

It will be observed from Table II that the application of lime has produced marked changes in the reaction of the surface soils of the various plots but it has exerted only slight

effect on the hydrogen ion concentration of the subsoils. It will also be noted that the subsoils under the Campbellsville and Berea soil fields tend to become more acid with depth. Certain possible effects of these varying reactions will be noted later in connection with the study of the root development of the clovers. In contrast, the Lexington field which is a soil derived from limestone, becomes more alkaline with depth except where the reaction of the surface soil has been modified by limestone applications.

MORTALITY STUDIES OF RED AND ALSIKE CLOVER

In each clover plot chosen for study an area one yard square was staked off. From time to time counts were made of the total surviving clover plants in these quadrats with the object of determining the periods of greatest mortality. The work was begun during the fall of 1921 so that the first quadrats were in first-year clover just going into the winter. In 1922 and 1923 the quadrats were located in the newly sown clover. The clover consisted of mixture of 2 parts of red clover (*Trifolium pratense*) and one part of alsike clover (*Trifolium hybridum*), seeded at the rate of 12 pounds per acre, thus giving an opportunity for a comparative study of these species. The seed was sown broadcast, in a winter grain, in February or March.

The data secured from the clover counts on the different quadrats are shown in Figures 1 to 7.

DISCUSSION OF RESULTS OF QUADRAT COUNTS

At Lexington it will be observed (Fig. 1) that the total number of plants on all plots is reduced decidedly but gradually thruout the life period of the stands. This reduction occurs both in the red and in the alsike clover, but generally it takes place more rapidly with the alsike than with the red clover. There appears to be no difference in rate of reduction in relation to soil treatments.

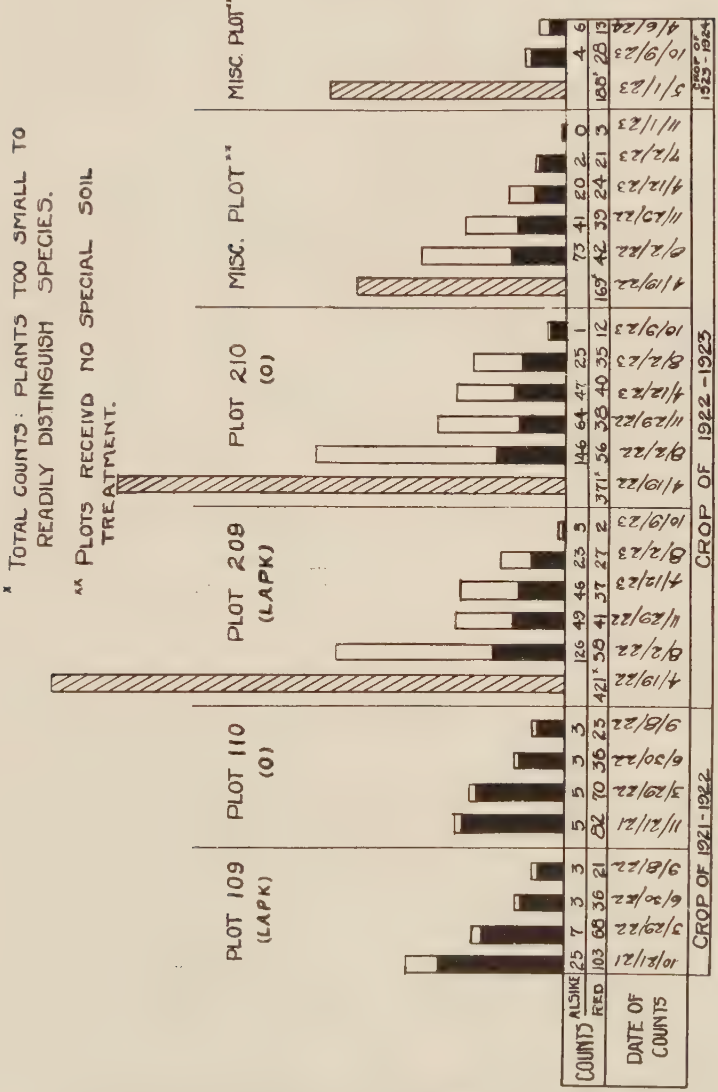
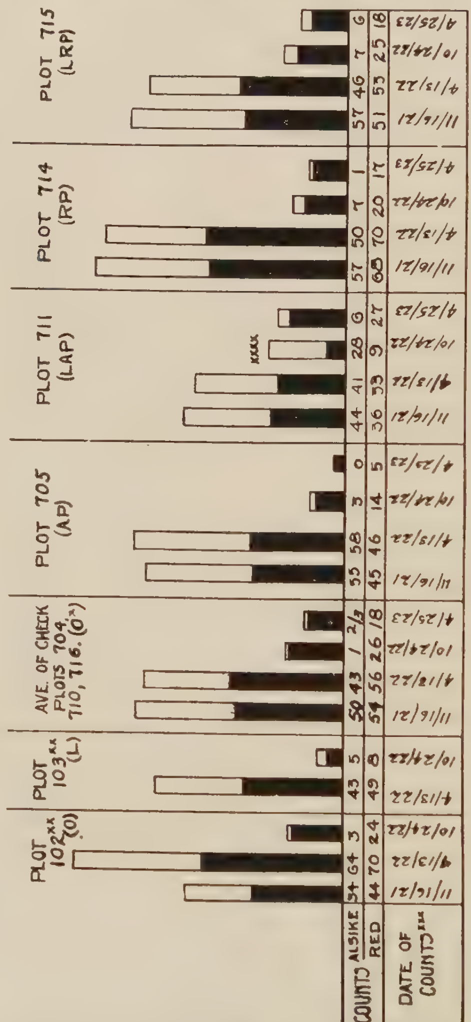


Fig. 1. LIVE RED AND ALSIKE CLOVER PLANTS ON SQUARE YARD QUADRATS, EXPERIMENT STATION FARM, LEXINGTON, KENTUCKY.

On the Campbellsville soil experiment field (Figs. 2, 3, 4) the reduction in total stand is not so gradual as at Lexington, but heavy during the first summer, practically nothing during the first winter and again marked during the second summer. The

second winter in the one set of counts made (Fig. 2) showed a very slight total loss again. It also appears that, speaking generally, the alsike clover stand is reduced more rapidly than the the red clover stand. The increase in the counts on plot 2 which



Crop of 1921-1922

Fig. 2. Live red and alsike clover plants on square yard quadrats, Campbellsville Experiment Field

* Check plots sometimes receive green manure crops of cowpeas between clover and corn crops.

** Plots 2 and 3 are in the general fertility experiments; remaining plots are in the phosphate experiments.

*** Plots 102 and 103 were plowed early in 1923 before counts were made.

**** Evidently a mistake was made in recording the counts on this date.

was recorded on April 13, 1922, over the previous fall count can not be explained. It may be a mistake in count; again, it may

have been due to the presence of a considerable number of seedlings. Such an explanation is given weight by the fact that the untreated Berea plot showed large numbers of such plants

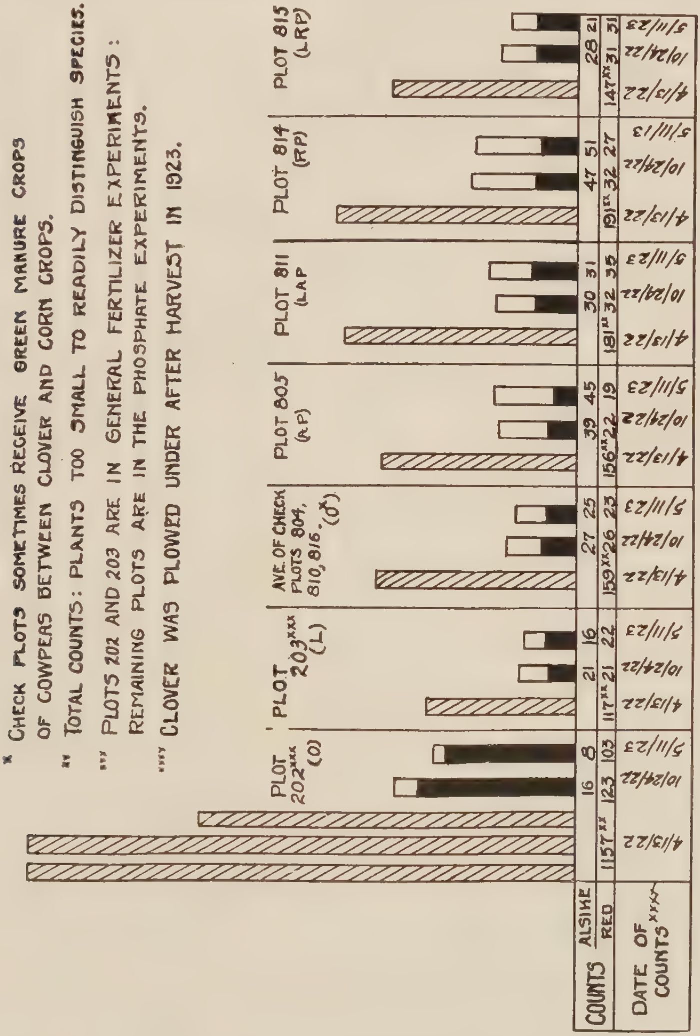


Fig. 3. LIVE RED AND ALSIKE CLOVER PLANTS ON SQUARE YARD QUADRATS, CAMPBELLSVILLE EXPERIMENT FIELD.
CROP OF 1922-1923

at the time of counting April 13, 1924. Inasmuch as the old plants were very small, it was almost impossible to distinguish

them from the seedlings at that time. The count made October 24, 1922, on plot 11 was undoubtedly misrecorded; the alsike clover and red clover counts being interchanged. The red-alsike

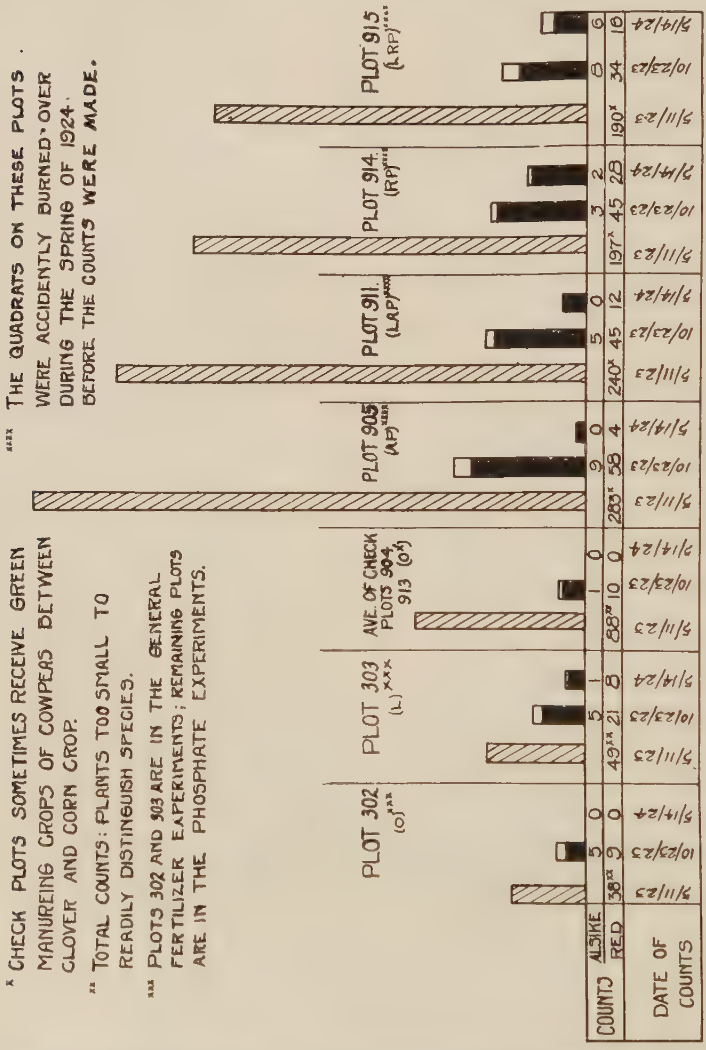


Fig. 4. LIVE RED AND ALSIKE CLOVER PLANTS ON SQUARE YARD QUADRATS, CROP OF 1923-1924 CAMPBELLSVILLE EXPERIMENT FIELD.

ratios on other plots tend to support this interpretation. Evidently a few other small mistakes in counts were made. Such

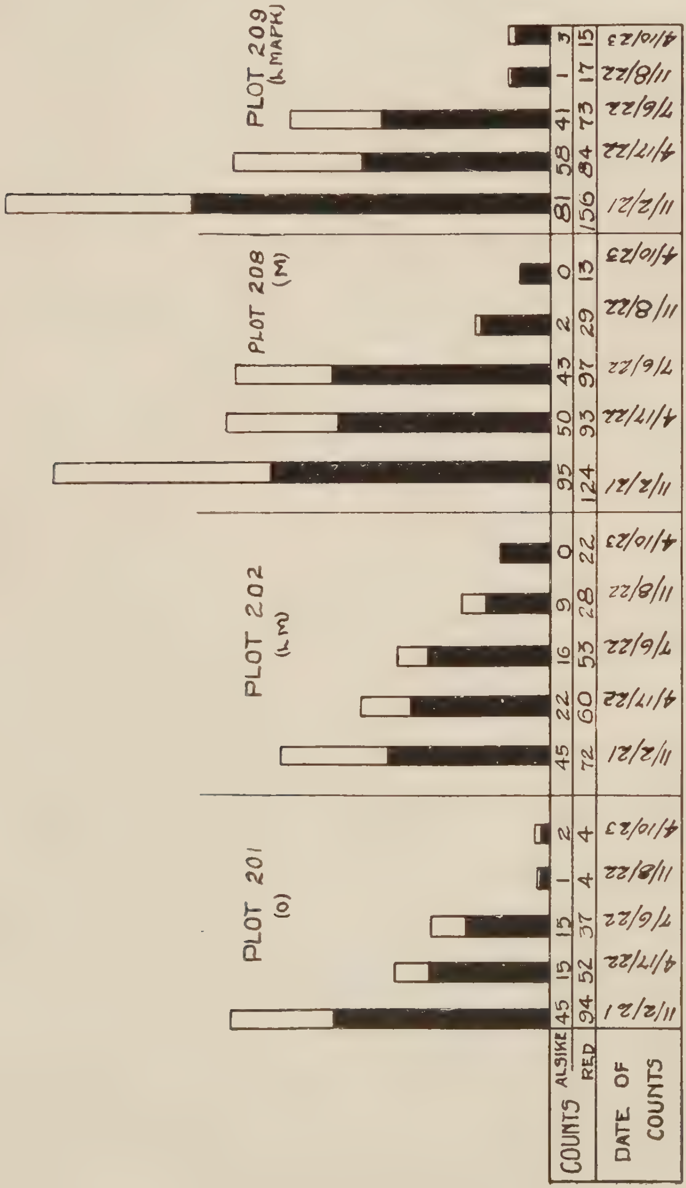


Fig. 5 Live red and alsike clover plants on square yard quadrats. Berea Experiment Field.
Crop of 1921-1922

are to be regretted, but were practically unavoidable. Where plants are crowded thickly, it is frequently impossible to distinguish between the separate small plants and the individual crown buds of a vigorous plant.*

On the Berea soil experiment field a difference in rate of stand reduction on the different plots is observed (Figs. 5, 6, 7). This reduction seems to be most rapid on plot 1, which is un-

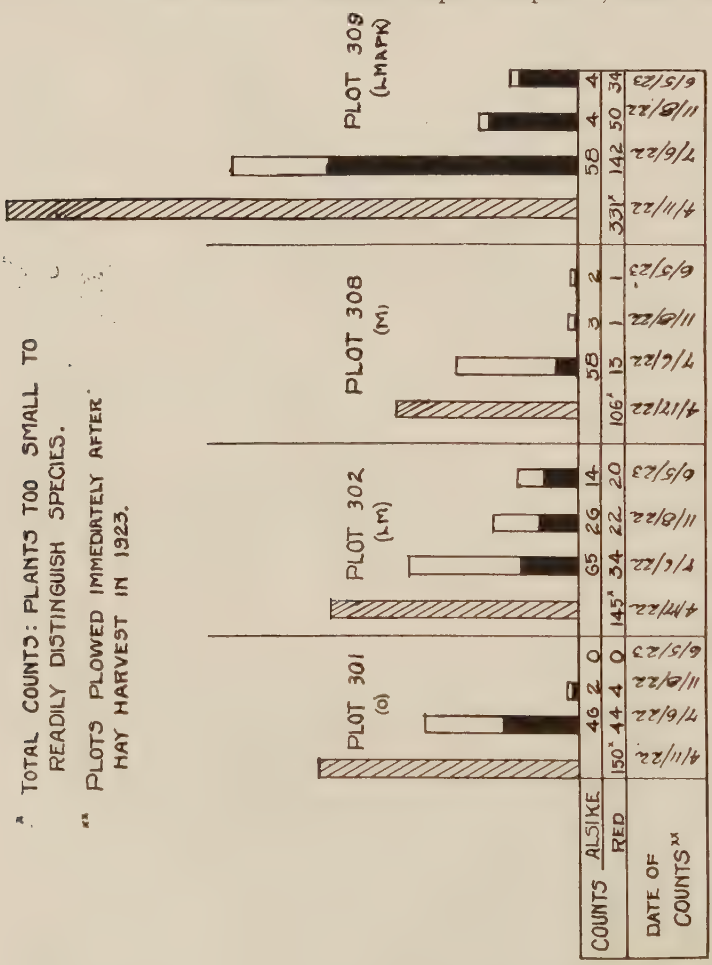


Fig. 6. Live red and alsike clover plants on square yard quadrats, Berea Experiment Field. Crop of 1922-1923

*The writers are indebted to Mr. J. F. Freeman, Supt. of Experiment Fields, for counts made on May 14, 1924, at Campbellsville.

treated, and least on plot 9, which receives manure, lime, phosphorus and potassium. Here again alsike clover seems to suffer a higher mortality than does red clover.

The winter losses on this field were heavier than those found in the other two fields, altho, as on the other fields, the summer losses are decidedly more pronounced.

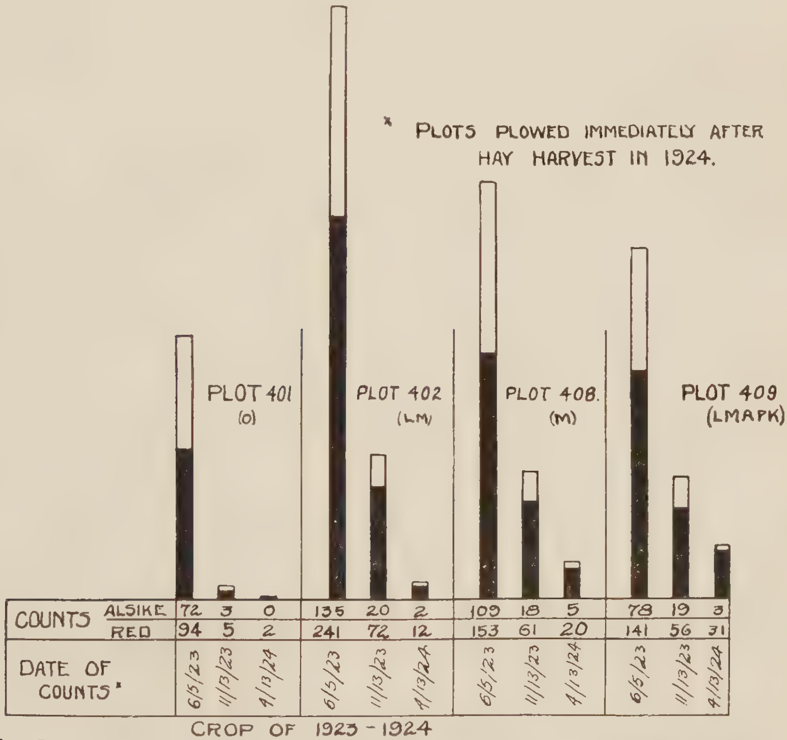


Fig. 7 LIVE RED AND ALSIKE CLOVER PLANTS ON SQUARE YARD QUADRATS, BEREA EXPERIMENT FIELD.

In order to make a more detailed analysis of the results of the counts shown in Figs. 1 to 7, *the changes occurring from one count to another* were computed in percentages. These are totaled by major seasons in Table III.

TABLE III.

Seasonal percentage decreases in stands of red and alsike clovers in quadrats on:

Lexington Soil Field

Crop of	Plot*	Clover	First Summer	First Winter	Second Summer
1921-1922	109 (RLAPK)	Total	....	41	68
		Red	....	34	69
		Alsike	....	72	57
	110 (O)	Total	....	14	65
		Red	....	15	67
		Alsike	....	0	40
1922-1923	209 (RLAPK)	Total	79	8	94
		Red	....	10	95
		Alsike	....	6	93
	210 (O)	Total	73	15	85
		Red	....	+5	70
		Alsike	....	27	98
	Misc.	Total	53	45	93
		Red	....	38	88
		Alsike	....	51	100
1923-1924	Misc.	Total	83	41	....
		Red	....	54	....
		Alsike	....	+50	....
Averages	All crops and all plots	Total	74	26	81
		Red	....	24	75
		Alsike	....	30	92

TABLE III—Continued

Campbellsville Soil Field

Crop of	Plot*	Clover	First Winter	Second Summer	Second Winter
1921-1922	102 (O)	Total	***	80	....
		Red	....	66	....
		Alsike	....	95	....
	103 (L)	Total	....	86	....
		Red	....	84	....
		Alsike	....	88	....
	Ave. of 704, 710, 716 (Checks) (O**)	Total	5	73	31
		Red	+4	53	31
		Alsike	14	98	33
	705 (MAP)	Total	+4	84	71
		Red	+2	70	64
		Alsike	+5	95	100
	711 (MLAP)	Total	8	50	11
		Red	8	***	***
		Alsike	7	***	***
	714 (MRP)	Total	4	78	33
		Red	+3	71	15
		Alsike	12	86	86
	715 (MLRP)	Total	8	68	25
		Red	+4	53	28
		Alsike	19	85	14

TABLE III—Continued

Campbellsville Soil Field

Crop of	Plot*	Clover	First Summer	First Winter	Second Summer
1922-1923	202 (O)	Total	88	20	
		Red.	....	16	
		Alsike	....	50	
	203 (L)	Total	64	10	
		Red	....	+5	
		Alsike	....	24	
	Ave. of 804, 810, 816 (Checks) (O**)	Total	67	9	Plots plowed after hay harvest
		Red	....	12	
		Alsike	....	7	
	805 (MAP)	Total	61	+5	
		Red	....	14	
		Alsike	....	+15	
	811 (MLAP)	Total	66	+7	
		Red	....	+9	
		Alsike	....	+3	
	814 (MRP)	Total	59	1	
		Red	....	16	
		Alsike	....	+9	
	815 (MLRP)	Total	60	12	
		Red	....	0	
		Alsike	....	25	

TABLE III—Continued

Campbellsville Soil Field

Crop of	Plot*	Clover	First Summer	First Winter
1923-1924	302 (O)	Total	63	100
		Red	....	100
		Alsike	....	100
	303 (L)	Total	47	65
		Red	....	62
		Alsike	....	80
	Ave. of 904 and 913 (Checks) (O**)	Total	88	100
		Red	....	100
		Alsike	....	100
	905 (MAP)	Total	76	94
		Red	....	93
		Alsike	....	100
	911 (MLAP)	Total	79	76
		Red	....	73
		Alsike	....	100
	914 (MRP)	Total	76	38
		Red	....	38
		Alsike	....	33
	915 (MLRP)	Total	78	48
		Red	....	53
		Alsike	....	25

TABLE III—Continued

Campbellsville Soil Field

Crop of	Plot*	Clover	First Summer	First Winter	Second Summer	Second Winter
Average of all Crops****	2 (O)	Total	87	27	80	....
		Red	....	22	66	....
		Alsike	....	62	95	....
	3 (L)	Total	59	31	86	....
		Red	....	29	84	....
		Alsike	....	35	88	....
	4, 10, 13, and 16 (Checks) (O**)	Total	72	13	73	31
		Red	....	12	53	31
		Alsike	....	13	98	33
	5 (MAP)	Total	71	25	84	71
		Red	....	45	70	64
		Alsike	....	0	95	100
	11 (MLAP)	Total	73	21	50	11
		Red	....	29	....	....
		Alsike	....	9	....	....
	14 (MRP)	Total	67	10	78	33
		Red	....	14	71	15
		Alsike	....	4	86	86
	15 (MLRP)	Total	70	17	67	25
		Red	....	14	53	28
		Alsike	....	22	85	14

TABLE III—Continued

Berea Soil Field

Crop of	Plot*	Clover	First Summer	First Winter	Second Summer	Second Winter
1921-1922	201 (O)	Total	....	52	93	+20
		Red	....	45	92	0
		Alsike	....	67	93	+50
	202 (ML)	Total	....	30	55	41
		Red	....	17	53	21
		Alsike	....	51	60	100
	208 (M)	Total	....	35	78	58
		Red	....	25	69	55
		Alsike	....	47	96	100
	209 (MLAPK)	Total	....	40	87	0
		Red	....	46	80	12
		Alsike	....	28	98	+200
1922-1923	301 (O)	Total	96	100	Land plowed after hay harvest	
		Red	....	100		
		Alsike	....	100		
	302 (ML)	Total	67	29		
		Red	....	9		
		Alsike	....	46		
	308 (M)	Total	96	25		
		Red	....	0		
		Alsike	....	33		
	309 (MLAPK)	Total	84	30		
		Red	....	32		
		Alsike	....	0		

TABLE III—Continued

Berea Soil Field

Crop of	Plot*	Clover	First Summer	First Winter	Second Summer	Second Winter
1923-1924	401 (O)	Total	95	75	Land plowed after hay harvest	
		Red	95	60		
		Alsike	96	100		
	402 (ML)	Total	76	85		
		Red	70	83		
		Alsike	85	90		
	408 (M)	Total	70	68		
		Red	60	67		
		Alsike	84	72		
	409 (MLAPK)	Total	66	55		
		Red	60	45		
		Alsike	76	84		
Average of all Crops	1 (O)	Total	95	76	93	+20
		Red	....	68	92	0
		Alsike	....	89	93	+50
	2 (ML)	Total	73	48	55	41
		Red	....	36	53	21
		Alsike	....	62	60	100
	8 (M)	Total	77	43	78	58
		Red	....	31	69	55
		Alsike	....	51	96	100
	9 (MLAPK)	Total	77	42	87	0
		Red	....	43	80	12
		Alsike	....	38	98	+200

*R = residues; L = limestone; AP = acid phosphate; K = potash salts; O = no treatment; M = manure.

"Misc." plots at Lexington received no specific soil treatments.

**These plots sometimes receive green manure crops of cowpeas between the clover and corn crops.

***Percentages not calculated because of obvious mistakes in counts.

****Doubtful counts on plots 102 and 711 of crop of 1921-1922 not included in these or other averages.

A study of the percentage decreases in stands of red and alsike clovers on the Experiment Station farm as shown in Table III reveals no annual or plot differences which are consistent or of sufficient magnitude, when considered in connection with Fig. I, to warrant any interpretation on the basis of soil fertility. There is, however, both in the decreases on the individual plots and in the averages, a pronounced variation in the seasonal decreases; the summer decreases, on the average, being approximately three times the magnitude of the first winter decreases. It will be observed, also, that wherever the red clover, and alsike clover plants are together in considerable numbers, the decreases, both summer and winter, are higher for the alsike clover. The averages probably express what may usually be expected in this respect on our most highly productive soils.

On the Campbellsville field (Table III) the same general total average seasonal decrease relationships hold as were observed at Lexington. Asike clover shows here, also, a higher summer mortality rate than red clover. The first winter loss of alsike, however, is higher only on the poorer plots. The second winter also alsike shows a higher average mortality than red clover.

It will be noted that the crop of 1923-1924 showed on four of the seven plots under study a greater loss during the winter of 1923-1924 than during the summer of 1923. Due to the fact that fire escaped from a nearby tobacco bed which was being burned and injured quadrats on plots 5, 11, 14, 15, and checks, counts on these plots cannot be accepted as representing the result of severe winter injury. Judging by unburned portions of the plots it is believed that plots 5, 11 and checks were more severely injured than plots 14 and 15, so that counts on the latter plots might be taken as indicating winter injury for the severe weather of the 1923-1924 winter.

The effect of soil treatment in holding clover stands on soils of low productivity, is shown very distinctly from the rates of decrease on the Campbellsville field (Table III). As an average of all counts, plot No. 2 (untreated) shows a decidedly heavier first summer loss than any of the treated plots. The greater per-

centage decrease of alsike clover than red clover on plot 2, irrespective of seasons, is striking.

Soil treatments on the Berea experiment field produced the same general variations in mortality rates as on the Campbellsville field (Table III). Plot 1 (untreated) shows the highest average percentage decrease in total stand for the first summer. It also leads in winter and second summer losses, the latter by smaller differences than for either of the other two seasons, however. Again it will be noted that, with the exception of one case, the alsike clover losses were always greater than the red clover losses.*

Data in Table IV show the effect of soil productivity on seasonal decreases of red and alsike clovers. Plots are thrown into various productivity groups on the basis of yields given in Table I. It will be observed that the percentage of plants dying the first summer is appreciably higher on the soils classed as "low productivity" than on the more productive soils. The same is true also for the first winter.

TABLE IV.

Average Seasonal Percentage Decreases of Red and Alsike Clovers in Quadrats on Plots of Varying Productivity.

Plots of*	Low Productivity			Medium Productivity			High Productivity		
	Total	Red	Alsike	Total	Red	Alsike	Total	Red	Alsike
First summer	81	....	....	72	....	....	74	....	....
First winter	39	34	47	25	31	14	26	24	30
Second summer	77	69	90	74	70	92	81	75	92
Second winter	40	34	79	25	28	44			

*Low productivity = Berea plots 1, 2, 8; Campbellsville plots 2, 3, 4, 10, 13, 16.
Medium productivity = Berea plot 9; Campbellsville plots 5, 11, 14, 15.
High productivity = All the Lexington plots.

The data in Table IV show that superiority of red clover over alsike clover in maintaining itself is more pronounced on

*Second winter increases in alsike on plots 1 and 9 are undoubtedly the result of slight mistakes in counts.

the soils of lowest productivity than on the more productive soils. The only exception to the above relative loss relationship, which is based upon a sufficient number of plants to be of value, is furnished by the first winter losses on soils classified as "medium productivity." It should be noted also that the alsike mortality rates of the second summer are of a very high magnitude and on the average vary comparatively little with soil productivity.

The fact that the highest summer loss on the soil of "low productivity" occurs during the first summer while that on the soil of "high productivity" occurs during the second summer, is of considerable significance. It determines that the stand of plants on the former soil will be much less than that on the best soil at harvest time.

Since data in Tables III and IV show that by far the greatest mortality of both red and alsike clovers, under the conditions of this study, occurs during the summer, the question arises as to which portion of each summer witnesses the most severe loss in stands. While midsummer counts unfortunately could not always be made on the same dates, they were made nearly enough in midsummer to indicate the answer quite conclusively. These data are presented in Table V. An average of all counts at Lexington shows the highest percentage loss of total clovers to occur during the later part of the second summer while other seasonal losses are approximately of equal values.

The data from the Berea field (Table V) show also a high late summer loss of total clovers. It will be noted in contrast to the results from the Lexington field that the later part of the first summer shows the highest loss on the least productive soil (Plot 1) while the greatest loss on the best plot (Plot 9), as at Lexington occurred during the later part of the second summer. While the periods of greatest mortality of red and alsike are identical, the losses of alsike always exceeded those of red.

TABLE V.

Average part-summer percentage decreases in stands of red and alsike clovers in quadrats on Lexington and Berea fields.

Plot Nos. and Treatment*	Berea Soil Experiment Field												Exp. Sta. Farm Lexington		
	1 (O)			2 (ML)			8 (M)			9 (MLAPK)			Average of all plots		
	Total	Red	Alsike	Total	Red	Alsike	Total	Red	Alsike	Total	Red	Alsike	Total	Red	Alsike
First part of first summer**	40			32			33			40			48		
Later part of first summer	95	94	96	71	66	77	75	63	87	69	63	83	46	42	55
First part of second summer	22	29	0	16	12	27	2	+4	14	20	13	29	42	35	55
Later part of second summer	90	89	93	46	47	44	78	70	95	84	77	98	67	61	82

*L = limestone; AP = acid phosphate; RP = rock phosphate; K = potash; M = manure; O = no treatment.
**For dates of midsummer counts see figures 1, 5, 6, 7.

Table VI shows averages of all plots and all counts,* and while recognizing inadequacies in the way of somewhat small quadrats, variations in times of counts, errors in countings, and small number of crops studied, it is believed the data represent what may usually be expected in Kentucky in the way of mortality rates of red and alsike clovers upon soils of varying productivity. It is believed that they warrant the following general statements:

1. That summer percentage losses usually are much larger than winter percentage losses, irrespective of soil productivity.
2. That winter percentage losses are highest on soils of lowest productivity.
3. That losses during late summer are larger than losses during early summer, and that these differences increase with decreased productivity.
4. That red clover usually will maintain itself better on the soil types studied than alsike clover, irrespective of soil productivity.

*Except plot 2, crop 1921-1922, Campbellsville.

TABLE VI.

Average seasonal percentage deceases in stands of red and alsike clovers in quadrats on soils of varying productivity, for whole and part seasons.

Averages of all Plots

Plots of*	Low Productivity			Medium Productivity			High Productivity		
	Total	Red	Alsike	Total	Red	Alsike	Total	Red	Alsike
Summer	81			73			75		
Winter	39	34	48	25	31	16	26	24	30
First part of summers**	25			34			46		
Later part of summers**	77	71	85	72	65	86	52	42	59

*Low productivity = Berea plots 1, 2, 8; Campbellsville plots 2, 3, checks.
Medium productivity = Berea plot 9; Campbellsville plots 5, 11, 14, 15.
High productivity = all Lexington plots.

**Campbellsville field could not be included since no midsummer counts were made there.

VIGOR OF RED AND ALSIKE CLOVERS ON SOILS OF VARYING PRODUCTIVITY

At the time the counts of red and alsike clovers were made on the quadrats previously discussed, notes were taken as to general vigor of the plants. These data are presented in Table VII. Inasmuch as the relative growth of the two clovers was found to vary but slightly from year to year, on any one date, the heights given in Table VII represent the approximate average heights of the two clovers for certain periods in the age of the crop.

TABLE VII.

Approximate Heights of Clovers on Soils of Varying Productivity.*

	Low Productivity		Medium Productivity		High Productivity	
	Red Clover	Alsike Clover	Red Clover	Alsike Clover	Red Clover	Alsike Clover
Fall, first year	2 in.	1 in.	6 in.	5 in.	9 in.	6 in.
Spring, second year	2½	1	6	5	6	4
Harvest	6	3	15	13	24	16
Fall, second year	2	1	4½	3	8	2

*See Table III for explanation of relative productivities.

The heights of clovers given in Table VII were secured by dropping a measuring stick into the clover, noting the general level of each clover and checking with averages of a few individual plants. It is recognized that a biometric study might have given slightly different figures, probably to the advantage of the red clover on the soils of medium and high productivity, but for the purposes of this study the measurements given are satisfactory.

WINTER HEAVING OF CLOVERS

A noticeable difference in the number of plants subject to winter heaving was observed on the different plots. Averaging the counts from these various plots it was found that red clover and alsike clover suffered 7.7% and 20.1% respectively on the

plots classed as of low productivity; 0.2% and 4.6% respectively on the plots of medium productivity, while showing no heaving on the highly productive soils. It is not to be undertsood that red clover never heaves on the soils represented by the Experiment Station farm at Lexington, but it is seldom of any importance. Even during the winter of 1923-1924 which caused considerable heaving of crops and an unusual amount of winter killing of red clover, there was practically no damage from heaving except in very limited areas.

Lime on the soils of lowest productivity greatly reduced the amount of heaving, cutting it from 6.8% to 3.6% for red clover and from 24.0% to 8.1% for alsike clover. These results were secured by averaging counts on Berea plot 2 and Campbellsville plot 3 for effects of lime and Berea plot 8 and Campbellsvile plot 2 for results on unlimed soil. The figures on heaving in soils of low and high productivity previously given were secured by averaging not only the plots just mentioned, but also Berea plot 1 and Campbellsville check plots which received no lime.

THE EFFECT OF SOIL PRODUCTIVITY AND SOIL TREATMENTS ON THE HEALTH AND DEVELOPMENT OF RED CLOVER ROOT SYSTEMS

First Season

Lexington Soil Experiment Field. The very young root systems of red clover growing on this field appeared upon casual examination to be entirely healthy. Careful examinations, however, always revealed one or more lesions (Fig. 8) on each system. The roots made rapid growth, however, thruout the first summer and fall, the taproots and primary laterals developing uniformly and reaching a maximum depth of about 30 inches by winter. From a casual examination of excavated root systems during the summer and fall, it appeared that the roots were healthy but a careful examination always revealed lesions on the smaller roots, and by fall many of the smaller roots had disappeared (Fig. 9*). The plants which had died showed variation

*In examining root systems a trench was dug in the clover plot of sufficient depth to allow work below depth of penetration of the roots and the taproot and several laterals were then carefully traced out, their penetration and health being noted at the time. Roots and root systems

A B C D

Fig. 8.—Root systems of young clover plants showing diseased areas (solid black). Plants A and B are alsike clover (Trifolium hybridum); C, sweet clover (Melilotus alba); D, red clover. Plants A, B and C were excavated from plot 309 (lime, manure, acid phosphate, potash treatment), Berea soil experiment field, when about 4 weeks old. Plant D was excavated from the untreated Lexington field soil when about 5 weeks old (summer seeding). These plants are representative of all clover and alfalfa plants of this age on all fields and plots studied. (x2/3.)

in root condition; in a few cases the roots appeared comparatively healthy, indicating that some plants had died from causes other than root injury. There was no apparent difference in root condition with plot treatments.

Campbellsville Soil Experiment Field. Each spring the roots on the young plants on this field appeared very similar to those on the Lexington field. By fall, however, marked differences had appeared. The depth of penetration varied from about 7 inches on the untreated plots to about 20 inches on the lime

illustrated in Figs. 8 to 12 were obtained by such excavations. It was found impracticable, however, to attempt to excavate whole large root systems for photographing because of the great amount of time necessary. Therefore, root systems illustrated in figures 13 to 17 were examined for penetration and lateral spread, then the soil was removed from about their outer limits. The soil within the boundaries of the systems was then removed by picking it out in small amounts or by washing. While this method did not give quite entire systems, it did give most of each and adequately illustrates the nature and condition of each system.

The abrupt termination of the taproots and larger laterals as shown in Figs. 13 to 17 usually represents locations of such serious lesions that the roots broke easily at these points.

Fig. 9.—A portion of a lateral from a first-year red clover root system excavated from Lexington soil experiment field Nov. 7, 1921. Note that many of the smaller roots are rotted wholly or in part (solid black), that only the rotted stub remains of some roots, while the main lateral appears healthy. Some of the healthy small laterals are of recent orgin. (x3/5.)

and acid phosphate plot. At that time the roots of the red clover plants on the untreated and check plots often presented brown or black lesions on the taproot with very few laterals below four inches. On the upper four inches, the taproot showed

a few dark brown or black summer laterals with a few bright new fall laterals replacing them. The taproot and older laterals were making no terminal growth. Fig. 10 shows a plant typical of the better on the check plots during the fall of the first year.

The roots in the best of the treated plots showed a bright, yellowish taproot with frequent large laterals of similar color

Fig. 10.—Root system of a typical first-year red clover plant from plot 710 (check plot), Campbellsville experiment field, excavated Nov. 15, 1921. Note the many dead roots, indicated by solid black lines; also the few laterals below 6 inches and the dead tip of the taproot at 7 inches. (x2/5.)

in the upper 6 inches of soil. Very few dark areas were present on these roots. New laterals were being produced both from the taproot and from larger laterals in the upper 6 inches of soil. Below 7 inches the taproot took on a dark brown or black color similar to those in the check plots and practically all laterals appeared dead. Both the taproot and larger laterals below the 7-inch depth showed numerous dark areas. They were producing few if any new laterals and were making no terminal growth The upper 6 inches of those root systems growing in limed plots were of a brighter, healthier color than were those root systems growing in unlimed plots. They also showed fewer lesions, dead laterals and replacement laterals than did those from the unlimed plots.

The depth to which the roots actually penetrated seemed to vary both with the nature of the subsoil and with the soil treatments; however, no roots were found penetrating the mottled gray clay lying below the yellow clay-loam subsurface stratum. Doubtless the slightly increasing acidity of the subsoil with depth (see Table II) was a factor in retarding root penetration, but the decreasing aeration was probably a factor of great influence, also.

Berea Soil Experiment Field. The roots of red clover growing on the Berea experiment field varied little from plot to plot during the early spring of the first season; all showed dark areas on the small roots irrespective of plot treatment (Fig. 8). With the coming of hot summer weather, however, differences developt in depth of penetration and appearance. By fall the penetrations varied from 8 inches on the untreated plot (Plot 1) to 15 inches on the plot receiving complete treatment (Plot 9). The roots on the plot receiving manure only (Plot 8) had reached a depth of 11 inches while the roots on the lime and manure plot had penetrated 14 inches. By fall the root systems of the plants surviving on the untreated plot were in a very poor condition (Fig. 11). The taproots were black thruout their length, and showed deep lesions penetrating to the central cylinder. The original laterals were apparently dead, new laterals had recently been put out from the upper three inches of the taproot and adventitious roots from the crowns of many plants. These new

Fig. 11.—First-season red clover root system from plot 201 (no treatment), Berea experiment field; excavated Nov. 8, 1921. The old root system is badly diseased (indicated by solid black in the drawing). Note also the many rooted stubs of original rootlets. The root system consists almost exclusively of new roots. (x¾.)

roots were for the most part short, tho some were as long as four inches. On the plot receiving lime, phosphorus and potassium (Plot 9) the roots growing in the plow depth of soil showed practically no dark areas except on the smallest roots and even here they were comparatively few. Below the 6-inch depth, however, conditions were very different, the roots appearing the same as those in the untreated plot. The taproots and larger laterals were

dark brown in color and showed many black areas. None of these roots were making terminal growth and most of the original smaller roots were dead. Many new roots had lately developt, a great majority of which were located in the upper 3 inches of the soil, arising from the taproot, larger laterals and crown.

It will be recalled that the subsoil underlying the Berea experiment field changes gradually, becoming at 15 inches a mottled gray silt loam. The roots seemed unable to penetrate this lower stratum of soil, always ending abruptly when they reached it. Inasmuch as the acidity of this lower layer was not widely different from that found just below the surface in plot 8 (Table II) which the roots were penetrating, it indicates that factors other than soil acidity were influencing root penetration. Here again lack of aeration may be an important factor.

The condition of the roots growing in the manure plot and the lime and manure plot was intermediate in character between the untreated and complete treatment plots. The roots in the manure plot seemed to be in slightly better general condition than those found in the untreated plot, while the roots in the lime and manure plot were but slightly inferior to those growing in the complete treatment plot (Fig. 12).

The Second Season

The root systems on the red clover plants growing on the Experiment Station farm at Lexington presented the same general condition in the early spring of their second year that they exhibited the preceding fall. Possibly they had penetrated a little deeper. They continued growth until about harvest time, reaching a maximum penetration of about 41 inches. At that time the ends of the taproots and larger laterals were alive, tho many dark lesions had appeared on the first year's growth. Most of the small laterals in the upper soil layers were dead. With the arrival of the hot, dry periods during July and August, nearly the entire root system of most plants died and decayed, so that it was practically impossible to excavate more than the heavier portions of the main roots. With the coming of fall rains, a few plants put out new roots from the crown and upper

Fig. 12.—Root system of a first-year red clover plant from plot 202 (lime, manure), Berea experiment field; excavated Nov. 8, 1921. This root system is typical of those systems growing in the treated plots of that field. Note the many rotted roots (solid black). Many of the healthy roots, especially near the crown, are of recent origin. Also note that practically all the roots arise from the upper 4 inches of the taproot and that practically all the laterals below 5 inches are rotted. (x1/3.)

portion of the taproot. These new roots made a maximum penetration of about 12 inches. The majority of plants produced no new roots and died by the coming of winter. (Fig. 13). It is the plants which put out new roots and the few which do not suffer serious root loss that come thru the second winter (Fig. 13, A).

Fig. 13.—Red clover root systems representative of those growing in the soil of the Lexington experiment field, fall of second year. Note the deep lesions on the taproots and larger laterals, and the difference in the number of new rootlets from the crown areas. A, represents the most vigorous and B, the least vigorous of those plants which were still alive. (x1/5.)

The Campbellsville Experiment Field. As on the Lexington field, the root systems of red clover plants on the various plots of the Campbellsville field came thru the first winter without important changes. Since there were no live tips on the taproots or larger laterals, the new growth originated from the roots put out the preceding fall. While these made rapid growth until

midsummer, they never quite equaled the penetrations of the first systems.

By fall the taproots and larger laterals on the untreated and check plots were apparently dead below approximately 1 inch from the crowns, the live root system consisting of new roots from the crowns and upper portion of taproots. These new roots were usually not over 3 inches in length and many showed dark areas on their surfaces (Fig. 14, A).

Fig. 14.—Red clover root systems from the Campbellsville soil experiment field, fall of the second year. A. Plants representative of those growing in the check plots. Note the dark lesions on the taproots and larger laterals and the new rootlets at the crown region of one plant (x1/3). B. A representative plant from plot 811 (lime, acid phosphate). Note the lesions on the taproot and larger laterals, also the new rootlets from the crown region (x1/5).

On the better plots at this time the root systems were similar to those of the same age on the Lexington field except that the new roots did not penetrate the subsoil. The abundance and vigor of these replacement and adventitious roots appeared to be a measure of the vigor of the plant (Fig. 14, B).

The Berea Experiment Field. The root systems of the red clover plants entering the second year on the Berea experiment field varied from plot to plot as they had the preceding autumn.

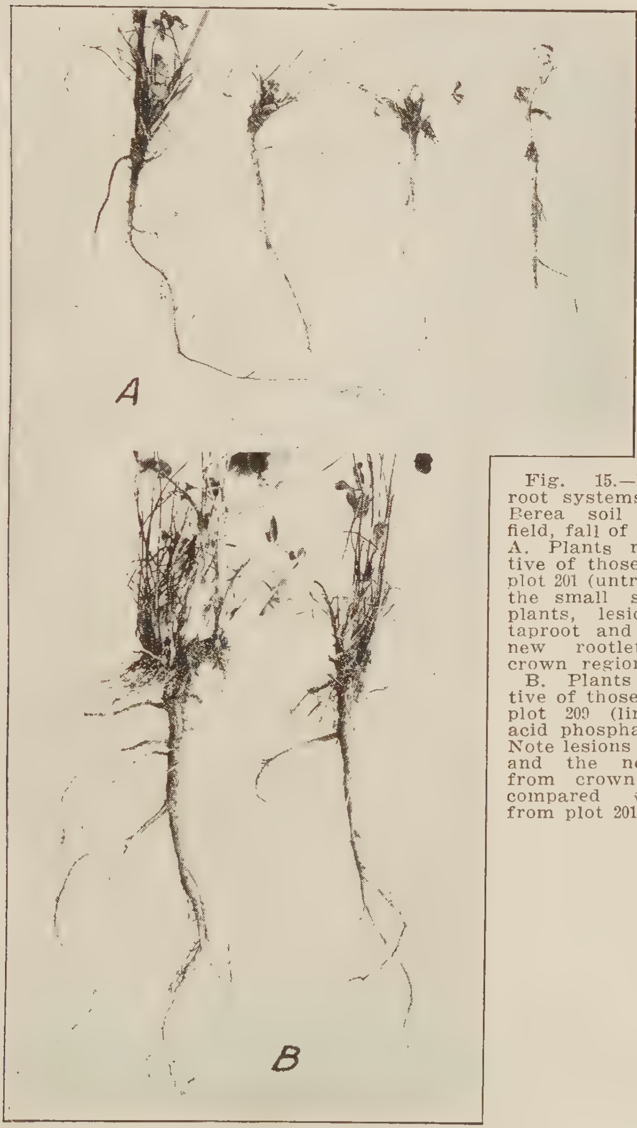
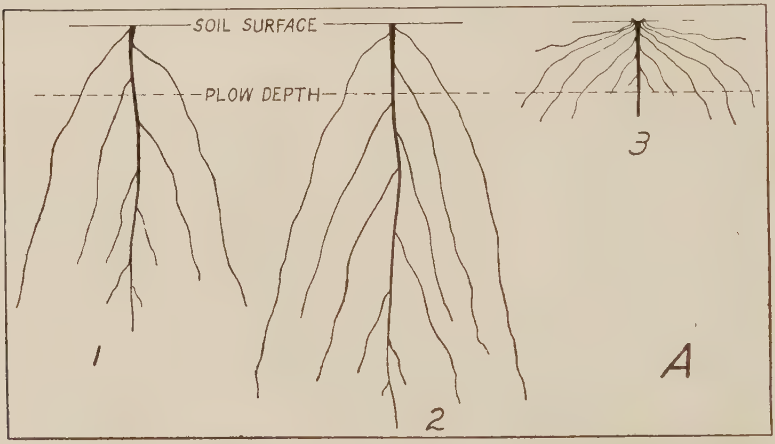


Fig. 15.—Red clover root systems from the Berea soil experiment field, fall of second year. A. Plants rerepresentative of those growing in plot 201 (untreated). Note the small size of the plants, lesions on the taproot and absence of new rootlets at the crown region. (x1/3.)

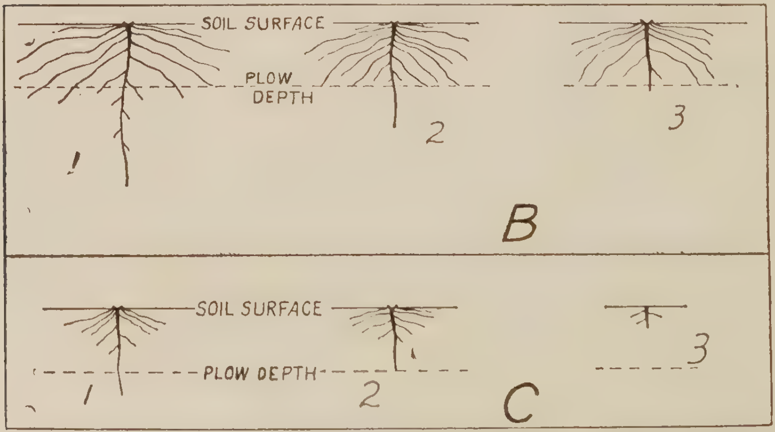
B. Plants representative of those growing on plot 209 (lime manure, acid phosphate, potash). Note lesions on taproots, and the new rootlets from crown region, as compared with those from plot 201. (x1/3.)

The live old roots and the new roots made a spring growth of about the same relative vigor as the tops and, as at Campbellsville, failed to attain the maximum penetration of their predecessors. By about harvest time these roots had made their maxi-

Fig. 16. A diagramatic representation of root penetration of red clover.



A. Lexingtno soil field. 1, root system of the first fall and second spring; 2, just preceding harvest; 3, late fall of the second year.



B. Systems from plot 9 (lime, manure, acid phosphate, potash), Berea soil field. 1, fall of first year and spring of second year; 2, just preceding harvest; 3, fall of second year.

C. Systems from plot 1 (untreated), Berea soil field. 1, fall of first year and spring of second year; 2, just preceding harvest; 3, fall of second year.

mum growth, and shortly after harvest most of them were dead. The surviving plants on all but the untreated plot put out new fall rootlets from the crown and upper portion of the taproots (Fig. 15, B). The very few plants on the untreated plot, however, behaved differently in that following the midsummer death of their roots they seemed unable to put out any or but very few new fall roots (Fig. 15, A) and consequently died by winter.

The variations in root development and root loss in relation to differences in soil productivity and to the nature of the subsoil, are shown diagramatically in Fig. 16.

ALSIKE CLOVER ROOT SYSTEMS

On all plots studied, the root systems of the alsike clover thruout the first year were inferior to the root systems of the companion red clover, both as to penetration and apparent health. The root systems of alsike clover seemed at all times more sensitive to poor soil conditions than were those of red clover. There were more lesions on the larger roots and more dead rootlets than on the red clover growing with them.

During the second summer, alsike root systems maintained about the same relative position to red clover that they held thruout the first summer. By fall the destruction of the original root systems was more nearly complete than was that of the red clover roots. The more vigorous plants produced new roots from the crown, but this rarely occurred on the untreated plots at Campbellsville and Berea (Fig. 17). In no case observed did these new individual roots reach the length of the new roots which the red clover plants put out under the same conditions.

It should be mentioned that on the rock phosphate and the lime and acid phosphate plots (Plots 11 and 14) on the Campbellsville field, the roots of alsike clover were at all times in nearly as good condition as were those of the companion red clover plants. On the other treated plots the red clover showed fewer dead roots and probably as a consequence fewer replacement roots than the alsike plants.

Fig. 17.—Alsike clover plants. A. Plants from plot 301 (no treatment), Berea experiment field, fall of first year, showing condition of alsike clover roots on a soil of very low productivity. Note the small size of plants and poor condition of root systems, also the few rootlets being put out from crown areas. (x1/3.) B. Plants from plot 811 (lime and phosphate) Campbellsville experiment field, fall of second year, showing all degrees of root conditions to be found on soils of medium productivity. Note the almost complete destruction of the old root systems and the new rootlets from the crown areas of some plants. (x¼.)

RELATION OF MORTALITY RATE TO ROOT LOSS

It will be recalled that on the average the highest percentage mortality of total clovers on the poorest soils occurred during the first summer, while on the best soil it took place the second summer, the losses on the medium productive soils being about equal for each summer (Table IV), and that late summer losses were usually much greater than early summer losses (Table V). These periods correspond in a striking way to the periods of greatest root loss. On the poorest soils, as has been shown, this occurred during the middle and later part of the first summer; on the soils of medium productivity it occurred during the middle and later parts of both summers, while on the most productive soils it was most apparent during the middle and later part of the second summer. With the disappearance of many or most of the roots large numbers of plants were unable to put out new roots and consequently died. It also appears likely that a considerable proportion of the winter mortality consisted of plants that had been able to replace but a few of the roots which they previously lost and so went into the winter in a condition which left them unable to survive it.

SUMMARY STATEMENT AS TO THE RELATION OF THE ROOT DEVELOPMENT, PENETRATION AND HEALTH TO SOIL PRODUCTIVITY

It should be kept in mind that the foregoing statement regarding this subject is general and applies to the average of plants. Individual plants differed at any time, some root systems being far superior to the average and others showing conditions below the average. The discussions as to root penetration, health and vigor represent the average conditions of each plot for the seasons under study. There were marked differences in these respects between plants growing on a given plot at any one time. Such variations in individual plants, it might be noted, apparently offer considerable opportunity for the selection and development of strains of clovers adapted to differing soil conditions. It should also be borne in mind that at any time after the middle of the first summer the statements regarding root systems apply to a group surviving varying plot mortalities.

For this reason the plants surviving on the poorest plots are probably potentially equal to the most vigorous plants on the most productive plots.

With these factors in mind, it is believed the following summary statements regarding the influence of varying soil productivity on the development of red and alsike clovers are justified:

1. That the depth of root penetration depends primarily upon the nature of the subsoil.
2. That the development of the tops is an indication of the extent of development of the root systems.
3. That the development of the root system during early spring following seeding varies but slightly with the soil productivity.
4. That with the advent of the warm spring and hot summer weather of the first year, differences in root systems corresponding with differences in soil productivity develop rapidly.
5. That the greatest penetration on the most favorable soils is reached about harvest time the second summer while on the least productive soils it is reached by the middle of the first summer.
6. That on the most favorable soils red clover enters the first winter with its original root system nearly entire and vigorous, while on the least productive soils it enters the first winter with practically a new set of secondary roots. On soils of medium favorableness it enters the first winter with an impaired original root system and many new roots.
7. That on soils naturally unfavorable to the growth of red clover, it may be grown with suitable soil treatments. However, practically the entire root system, in such soils, will be found in the plow depth of soil.
8. That even on the most favorable soil the original root system of red clover becomes impaired by harvest time of the second summer and during the hot summer weather following, most of it disappears.
9. That by the end of the second summer the functioning root systems of red clover will consist of new roots put out from the crown and upper portion of the original root system. These new roots are put out with the coming of late summer and early fall rains.
10. That the season of greatest mortality for red clover plants on any one soil corresponds with the season in which the root loss is greatest (except, of course, where death is due to an epidemic of crown rot, anthracnose, etc.).
11. That on the least favorable soils the red clover plants have lost two root systems by the middle of the second summer and seem unable to put out a third.
12. That under the conditions of this study alsike clover root systems always appeared less healthy than those of red clover of equal age and in the same environment.
13. That red and alsike clover plants as a group are not typical biennials morphologically, but largely assume the biennial habit due to the gradual destruction of their root systems and the inability of most of the plants to survive the hot, dry periods following harvest of the second year.

THE EFFECT OF PARTIAL SOIL STERILIZATION ON THE DEVELOPMENT OF CLOVER PLANTS

During the spring of 1923 one-half of a plot of ground was sterilized with a tobacco bed steam sterilizer. Red clover was shown alike on the sterilized and unsterilized portions. After about three weeks a difference in growth was noted, that on the sterilized portion being somewhat larger. This difference increased until the clover on the steamed portion reached full bloom. At that time it had reached a height of about 22 inches while that on the unsteamed portion was but 10 inches tall and showed only an occasional blossom (Fig. 18). The clover was

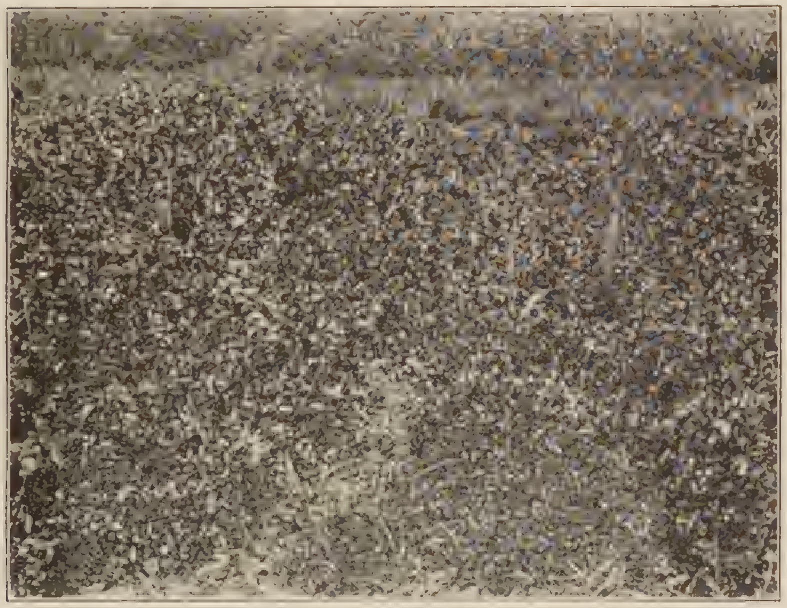


Fig. 18.—Red clover on steamed (left) and unsteamed (right) soil, Experiment Station farm, Lexington, seeded Mar. 28, 1923, at rate of 10 pounds per acre; photographed July 2, 1923, when clover on left was 18 inches and on right 5 inches high. Note the equal sized stakes in the centers of the plots. Two weeks after photographing the heights were 22 inches and 10 inches, respectively. Note the bloom on clover on left while none shows on right. Soil steamed with tobacco bed steaming outfit.

clipt at this time. By fall each part had practically repeated its earlier growth. An examination of the root systems of plants growing on the two plots revealed root differences as striking as

the top differences. In the first place there were many more small roots in the upper five-inch stratum of the steamed soil than in the corresponding area of the unsteamed soil; but more striking and probably more significant, there were practically no lesions

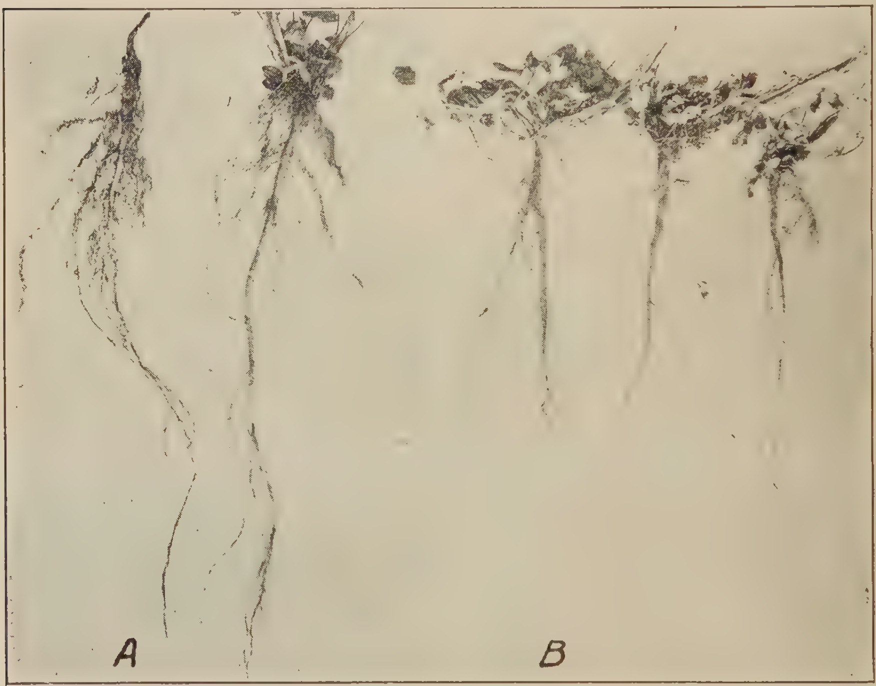


Fig. 19. Red clover root systems; A, developt in steamed and B, in unsteamed soil. Plants dug from plots shown in Fig. 18, on December 12, 1923: observe the many more lateral roots on the upper 5 inches of the taproots on those of A than on those of B. The more healthy condition of the upper portion of the roots of A than of B is indicated by the color of the taproots. (x1/5.)

on any of the roots in the top five-inch layer of the steamed soil while lesions were numerous on the roots in the upper five-inch layer of the unsteamed soil (Fig. 19). The latter also showed many stubby rotted roots while the former showed practically none. Below the five-inch depth both systems were alike, and showed many dark lesions and dead rootlets. While the maximum penetrations were not accurately determined, there did not appear to be much difference between the root systems from the two

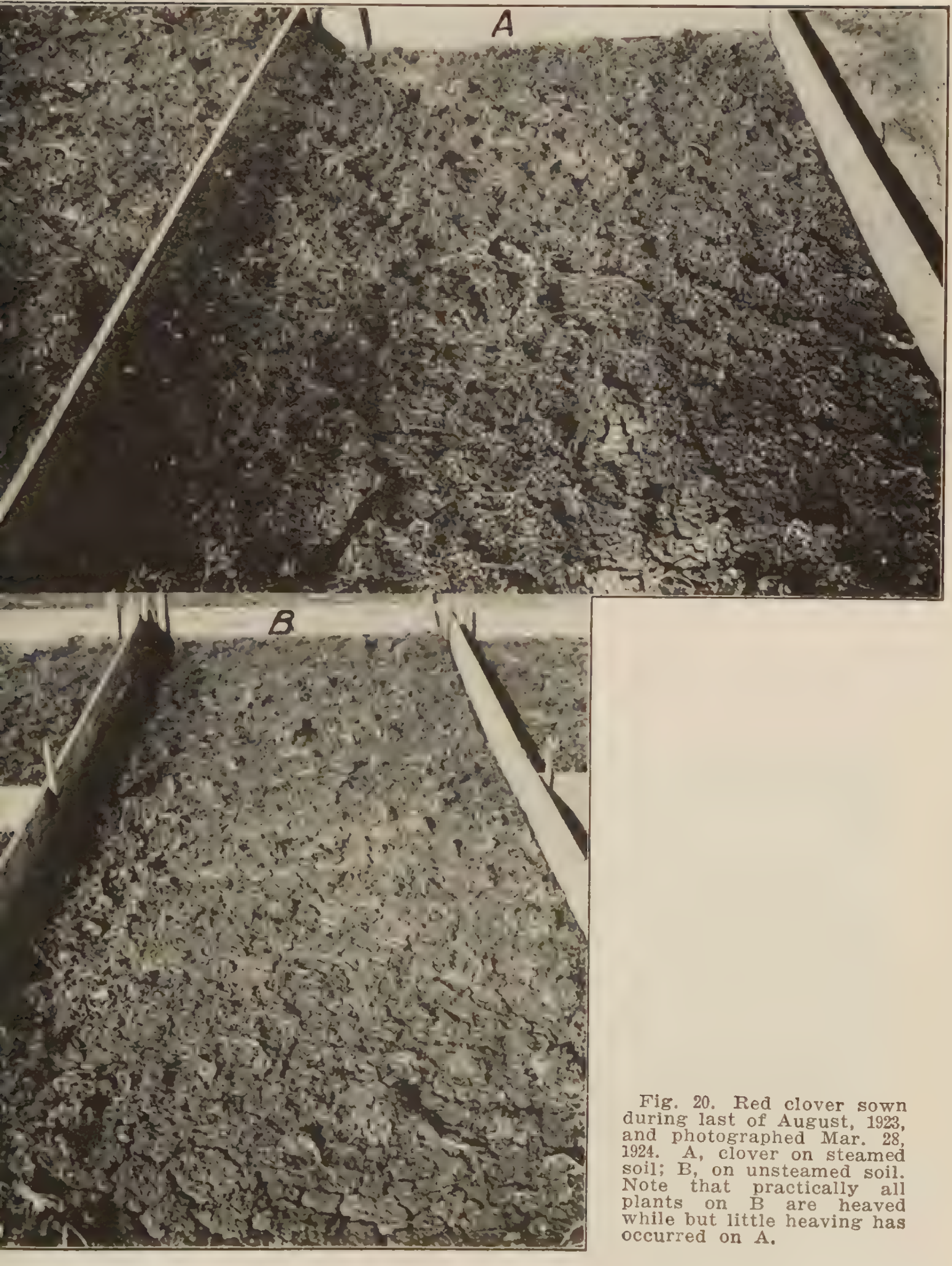


Fig. 20. Red clover sown during last of August, 1923, and photographed Mar. 28, 1924. A, clover on steamed soil; B, on unsteamed soil. Note that practically all plants on B are heaved while but little heaving has occurred on A.

plots in this respect. This plot was allowed to go into the winter without clipping. During the winter the plants on the unsteamed portion winter-killed much worse than those on the steamed area. On April 15, 1924, counts in 7-ft. x 12 ft. areas showed 73 plants on the steamed area and 18 plants on the unsteamed part. The plants on the steamed portion were much more vigorous. This difference largely disappeared, however, by harvest time when the clover on the steamed portion measured 22 inches while that on the unsteamed portion averaged about 20 inches.

The test was repeated on another pair of plots, seeding the last of August, 1923. By winter the clover on the steamed area had made a growth of 3 inches while that on the unsteamed portion was scarcely 1 inch high. The crowns of the former were much more vigorous. During the winter the clover on the unsteamed section heaved badly and completely winter-killed while that on the steamed portion showed practically no heaving and comparatively little winter-killing (Figs. 20, 21). While there was no red clover with which it could be compared accurately during the preharvest growth, the clover on the steamed soil

Fig. 21.—Red clover sown last of August, 1923, and photographed July 18, 1924. A. Clover on steamed soil; B, on unsteamed soil. Height, on steamed soil, 20 inches; on unsteamed soil, no clover. Compare with Fig. 20.

seemed to begin its spring growth somewhat more vigorously than other second-year red clover on the farm. It failed, however, to make any larger final growth or reach maturity any earlier. An examination of the roots revealed that those in the upper 6 inches of soil were bright, and showed very few dark lesions on the smaller roots. The larger laterals and taproots, however, showed many dark areas. Below the 5-inch depth all roots showed many lesions. Roots growing in unsteamed soil on the farm showed many dark lesions both on the small and large roots.

It, therefore, appears that much of the red clover mortality must be closely connected with root injury, its death whether from heaving or otherwise being caused directly or indirectly by factors producing the injury.

THE CAUSE OF ROOT INJURY

A survey of the literature reveals a few records of root diseases of red clover. Violet root-rot, caused by *Rhizoctonia violacea*, was described in Great Britain in 1906 as injuring red clover (26). According to Ware (46), Ericksson reported the same disease from continental Europe in 1912. Recently it has been found (46) to be causing some injury again in Great Britain. Stevens and Wilson (39) found a Rhizoctonia on the roots of red clover in North Carolina in 1911 and reported it as the cause of the devastation of entire fields of red clover in that state. Peltier (31), in 1916 reported *Rhizoctonia solani* as causing damping off of red clover seedlings in the greenhouse. In 1920, Selby (36) found a Fusarium root-rot of red clover seedlings in scattered localities in Ohio. The same injury was found more widespread in 1921 (37), causing very serious damage to certain fields. Clayton (10) reported that a root-rot of red clover caused by *Fusarium sp.* was rather generally distributed over western and southeastern Ohio in 1921, causing serious damage in certain localities. Young (50) has found a wilt of red clover caused by a root-rot due to various species of Fusarium He states that injury under natural conditions depends upon increased susceptibility due to the weakening of the plants by

various causes. A later report from this worker (51) states that he has found several species of Fusaria which, tho producing lesions on the roots of red clover in the greenhouse, failed to kill the plants outright.

Red clover roots of various ages have been examined by the writers not only in many sections of Kentucky but also in several northern and eastern states. Without exception the same general type of injury has been found on each plant examined, varying, of course, in severity from place to place and with the individual plant. These observations suggest that this type of injury is coextensive with the cultivation of the clovers, at least in the older clover sections of the United States.

It is probable that the diseases noted by the investigators mentioned and attributed to different organisms represent examples of the same disease.

The present study has not progressed to the point where a definite statement can be made as to the cause of the disease. However, some observations have been made and studies conducted which may be of value in indicating the nature of the malady.

The results of the partial sterilization tests on clover in the field suggest that the disease is due to pathogenic soil organisms, as, following steaming, the roots which developed in the soil thru which the steam penetrated were free from lesions and remained free for rather long periods, while the roots in the lower layers into which the steam did not penetrate were no more healthy than those in the unsteamed plots. We recognize that increased top growth of plants possibly may result from the liberation of plant foods due to the treatment, but the marked difference in health of the roots developed in the treated and untreated layers of soil we believe can only be explained on the assumption that partial sterliziation destroyed some pathogenic micro-organism in the treated layer.

The primary injury to the roots, especially the largest ones, appears to be limited to the cortical layer as even after the taproot takes on a black, decayed appearance thruout nearly its entire length, new rootlets may still develop from the central

cylinder (Fig. 11). In the case of the smaller roots, the injury appears to penetrate beyond the cortex, since the death of these roots sooner or later follows after cortical infection.

ISOLATION STUDIES

Isolations have been made from the small, rotting rootlets of red clover, alsike clover and alfalfa, as the same general condition exists with respect to rotting of the small rootlets of all the commonly cultivated legumes. There is no consistency in the organism isolated from the roots of any species, altho care has been used in the selection of material for this purpose.

Twenty-four cultures of Fusaria have been isolated from red and alsike clover roots. These appear, from studies so far conducted, to represent several distinct species, including a *Fusarium moniliforme* distinct in cultural reactions from the corn organism, isolated three times; *Fusarium solani* (Mart.) App. et Wr., isolated twice, and an organism like *Fusarium oxysporum* isolated once. The remaining organisms have not yet been identified. From alfalfa roots 14 cultures of Fusaria have been isolated, of which seven appear to be distinct from the rest and have been isolated once each; four others appear identical and three others appear to represent another species. All the Fusaria isolated belong either to the section Elegans or Martiella. Besides these, several other genera of fungi have been isolated one or more times from the clover roots.

SEED-BORNE ORGANISMS

In preparing seedlings for inoculation *Altermaria sp.* has been isolated ten times from different lots of clover seed. A sterile fungus which produces a rather profuse growth of rust colored hyphae on potato dextrose agar has been isolated three times from clover seeds. The seeds from which the isolations were made had been treated twenty-five minutes in a 1:250 formalin solution at 40°c. and germinated on agar in petri plates. The necessary precautions to prevent accidental contamination were

taken thruout. Thus far, with the exception of occasional bacterial colonies around seeds, no other organisms have been isolated from seeds so treated. There is evidence that *Bacillus radicicola* may escape this seed treatment as occasionally clover seedlings transferred to tubes of nutrient agar develop nodules.

INOCULATION STUDIES

In attempting to determine whether or not the organisms isolated from clover and alfalfa roots and seeds were pathogenic, inoculations were made on red and alsike clover and alfalfa seedlings growing in tubes of nutrient agar. Seedlings of various ages have been used, from those just beginning to produce the first true leaf to seedlings well rooted and with three or four true leaves. The seedlings were prepared by treating the seed as indicated in the preceding paragraph, germinating them on agar in culture dishes and when well started transferring those that were free from micro-organisms to test-tubes containing about 10cc of nutrient agar. The plants make fairly rapid growth in this medium if exposed to sunlight.

The inoculations have all been made by transferring a small piece of mycelium from a pure culture of the organism to be tested to the surface of the agar.

In the case of the most injurious organisms the seedlings are killed in a comparatively few days. The organism generally attacks the seedling at the surface of the agar and causes a typical dampening off, the seedling falling over and the top gradually dying. Occasionally, altho a seedling may appear to be rotted at the base, it will remain alive for days but make no further growth. The less injurious organisms usually kill the seedlings in time but the period to death is much prolonged; especially is this true if the plants are older and have formed two or more leaves and the stem tissue is fairly hard.

In some cases the plants may persist for over a month, showing comparatively little effect from the organism and continuing to grow as long as the agar remains moist enough to sustain growth. Occasionally, even with quite injurious organisms, the older seedlings may not be killed even tho the roots are nearly

completely rotted. These are cases in which the plants had grown long enough before inoculation to have synthesized considerable food materials. When the culture of the fungus has become stale and ceased growth the plant may develop a new root system which penetrates thru the fungus and into the agar without injury. This power of root replacement is likewise made use of in the field, as we have noted, when the root systems have been almost completely destroyed during a period of unfavorable conditions.

Under the conditions of the test almost all the organisms isolated from the roots of these plants appear capable of causing severe injury to clover and alfalfa seedlings. *Fusarium moniliforme* from corn has proved on several occasions to be less injurious than the fusaria isolated from roots of clovers and other plants. It has also proved to be less injurious to clover and alfalfa than a strain of the same fungus isolated from clover roots. The seed-borne organisms, altho slightly injurious, act much more slowly than the fusaria from the roots. From the results obtained so far, it appears that the organisms commonly carried in the seeds of clovers will play far less part in the clover root-rot problem than those commonly found in the soil.

If these tests are any criterion of what takes place in the soil, it appears that several species of fusaria are concerned in this problem. To determine the effect of other species of fusaria on clover roots, named cultures of fusaria were obtained from the Minnesota Agricultural Experiment Station and used for inoculating red clover and alfalfa seedlings. The following organisms have been found to kill alfalfa and clover seedlings on nutrient agar, in test-tubes, in a period of nine days or less:

Gibberella saubinetii
F. conglutinans callistephani
F. oxysporum
F. lini
F. radicicola
F. martii
F. conglutinans
F. discolor var. sulphureum
F. oxysporum var. asclerotium
F. batatatis
F. orthocerus triseptatum (probably F. solani)
F. lycopersici

Fusarium hyperoxysporum had not killed either the alfalfa or the red clover seedlings in 18 days, altho the plants appeared to be slightly injured.

In addition to the fusaria mentioned, isolations from rotting tobacco roots, representing apparently at least twelve distinct species, have been tested on clover and alfalfa seedlings and found to kill them as readily as the before mentioned species. These fusaria almost without exception belong in the sections Elegans and Martiella. These results and the results of numerous other inoculations (42) on soybeans, corn and other plants, suggest quite strongly that the commonly isolated root fusaria are capable of injuring the roots of a considerable number of distinct species of plants under the most favorable conditions. Whether or not they play the part of primary pathogens on the small roots of the crop plants from which they have been isolated or whether they enter immediately after some more virulent pathogen which is much more difficult to isolate, has not yet been determined definitely, altho the latter view appears to be the correct one in the case of corn (43). Further careful study of this phase of the problem will be necessary before any definfiite conclusion can be drawn as to the direct cause of clover root injury.

DISCUSSION

This study has shown that while a very definite clover failure exists on certain soils it is but the intensification of a death rate in all stands of clover which occurs on the best of the cultivated soils. Probably anything which constitutes an unfavorable factor for clover contributes to that failure.

Low productivity of the soil appears to be conspicuously associated with these failures. Whether this is due mainly to lack of nutrient minerals or to an unfavorable hydrogen ion concentration or to other causes cannot be answered on the basis of our studies. It appears that the H-ion concentration is a factor of great influence, since root penetration always ceases more or less abruptly when the roots reach those subsurface soils of pH 5.00 or less. On the other hand, penetration proceeded uninterrupt-

edly at pH values above 5.00 if the soil showed evidences of proper aeration. On the basis of these observations it appears that the critical H-ion concentration for red clover is about pH 5.00. While this value is silghtly higher than Bryan (6) found, it is somewhat lower than those secured by Hasselbach (20). The former found pH 4.0 to represent the approximate value tolerated, while the latter's results indicated pH 6.0-6.3 to be critical.

The evidence also indicates that other factors influence root penetration. It will be recalled that root development was generally much better on soils receiving lime and phosphate than on those plots receiving lime only, thus indicating that differences in the nature of surface treatment cause differences in root penetration. Again, the depth of penetration was found to be directly proportional to evidences of aeration, indicating either that aeration itself or factors associated with it exerted a dominant influence upon the root development. Doubtless all factors are so interdependent that it will be impossible to fully analyze the effect of any one.

The differences to which the red clover roots penetrated into the different soils appeared to be closely correlated with the development which the plants made above ground. This apparent relationship is shown by the following data in which top development is expressed as yield of hay:

Soil Field	Plot	Yield of Clover Hay	Maximum Root Penetration
Lexington	9 (RLPK)	4425 lbs.	41 ins.
Campbellsville	11 (LAP)	2863 lbs.	20 ins.
Berea	9 (LMAPK)	1932 lbs.	15 ins.

As a species, red clover is a taproot plant with little tendency for the roots to branch, beyond the production of relatively few laterals. When it grows into a soil which will not permit its root development to the fullest length, it seems unable to secure sufficient soil nutrients from the area in which its roots develop to permit the maximum growth of its above-ground parts

even if the soil has been liberally fertilized. Obviously, for growing taproot plants on an unfavorable soil, the suggestion is to develop a deep surface soil properly limed and fertilized.

The fact that maximum root penetration on the best plots of the Campbellsville and Berea soil experiment fields was increased over that on the check plots by the application of lime, manure and fertilizers, indicates either that the materials applied had penetrated more or less into the subsurface soil, or that the plants growing on the treated soils were, because of superior vigor, somewhat more successful in penetrating the unfavorable subsoil; each successive crop thus profited thru the organic matter which the roots of the preceding clover crop left in the upper subsoil, thus penetrating slightly deeper than the preceding crop. While admitting the possibillity of the first explanation, it appears to the writers on the basis of observations that the second suggestion has more merit. The fact that penetration was in direct proportion to the yield response, i. e., vigor, seems to indicate the soundness of this hypothesis. It seems improbable that depth of fertilizer diffusion would vary noticeably with different fertilizer combinations, while it is established that plant vigor and yield do vary with differing combinations. On the other hand, it must be granted that the fertilizer which may be sufficient for supplementing the nutrients in the plow depth of a cropped soil, may be quite inadequate to produce a subsoil of improved productivity. Subsoil productivity appears to be a field which has received insufficient study and a most promising field for investigation.

Considerable variation exists in the morphology of red clover roots, certain plants having a tendency toward a more branched system. While such plants do not differ markedly from type plants on deep rich soils, they appear different in fertilized surface soils which are underlaid by subsoils of low productivity. It seems that they more thoroly utilize such surface soil than do type plants and are more or less successful in maintaining themselves on these soils, while the type plant languishes and dies prematurely. The apparent superiority of these branching root

types suggests the possibility of securing superior strains for shallow soils.

Alsike clover also has a taproot system but it differs from red clover in that it seems to develop a larger number of adventitious roots from the stems, standing between red clover and white clover (*T. repens*) in this respect. This rooting habit would seem to make it well adapted to shallow soils; the fact that it does not appear to be so under the condition of our study must be taken as indicating that it is not so well adapted either to our weather or to our soils, or both. It appears as the result of our studies that the common opinion that alsike is more winter hardy, more heat resistant and better adapted to poor soils than is red clover (32), is open to serious question or to qualification as regards this region. That it may be better adapted to cool weather, probably is true. Probably it is true, also, that alsike is better adapted to wet soils, due to the fact that it can adapt itself to surface growth by adventitious roots from the crown and stems.

It appears that these studies have thrown some light on the phenomenon of heaving. As has been described, heaving was worst on the poorest soil, becoming progressively less to the best soil. This graduation exactly parallels root development. It seems, therefore, that heaving results because a plant's root system is inadequate to withstand the lifting power of the freezing soil in which it is growing. That such an explanation is valid is strengthened by studies which we have conducted upon the development of sweet clover. Among other features, these studies have indicated a direct correlation between prevalence of heaving and lack of root development, irrespective of the cause of such poor development. It is, of course, recognized that differences in "heaving power" of soils exist, due, apparently, to differences in the physical condition of the soil, but it seems apparent to the writers that differences in amounts of heaving which may occur within a stand on any similar physical habitat may be traced directly to differences in root development. These differences may result from differences in soil fertility, from variations in cultural practises (time of seeding, clipping, etc.), from disease or insect injury, etc.

That a plant with a root system which for any reason is unable to develop normally should easily fall a prey to root pathogenic organisms seems logical, not because the tissues of such roots are necessarily more susceptible, but because the root system is unable to restore or replace itself. The lack of resistance of the roots growing in the most productive soil is clearly demonstrated in Fig. 9. The fundamental difference between the roots growing in the best and poorest soils seems, therefore, to lie in the relative rates of growth of the pathogenic organisms and of the root systems, with the latter as the larger variable. On the best soil the roots grow rapidly and replacement appears easy while on the poor soils, with slower root growth and slower replacement, the disease causes relatively more injury. If the red clover is growing in a poor soil or satisfactory surface soil and unsuited subsoil, it appears unable to develop its taproot system and unable to make adaptation to the situation by putting out numerous new roots; consequently it rapidly loses its functioning root system because of the pathogenic organisms which seem always to be present in cultivated soils. The survival of a comparatively few plants in every stand, which seem to be adapted to such unfavorable conditions, suggests the possibility of selecting adapted strains for such soils.

There is the probability, also, that the individual plant is influenced in its synthetic processes by changes in temperature so that it becomes much more susceptible to attacking organisms. It will be recalled that the greatest root loss was found to occur during the hot weather of summer. The work of Dickson, Eckerson and Link (11) in which it was shown that unfavorable temperatures for the development of corn and wheat seedlings predisposed them to seedling blight by *Gibberella saubinetii*, indicates a very probable cause for increasing susceptibility of red and alsike clovers during hot summer weather.

Again, the fact that on the best soils almost the entire root loss occurs, about the time when the crop is harvested, suggests a physiological change coincident with either naturation or clipping at harvest which predisposes the plant to attack from injurious organisms. Storer (40) many years ago noted root loss

of red clover at certain stages in the life of the plant. He reported that the plant developt a new system of laterals each spring from the materials stored in the taproot. He called attention further to the habit of the plant in forming many new rootlets after clipping, before any new shoots were put out above ground. In the main our results agree with these observations. The failure of the plants on the Lexington soil to produce a wealth of new roots during the second spring is a notable exception, however. We believe that this behavior of the plant during the second spring, on the Lexington field, indicates the normal habit of the plant and that any deviation from this is due to unfavorable factors of environment which predispose the plant to attacks from organisms that more or less completely destroy the first season's root system.

The suggestion is quite apparent, therefore, that clover failures are directly related to root loss, and that root loss is due to attacks of injurious organisms which cause more or less severe injury because of the unfavorable ecological relations of the plant. The full proof of this suggestion and its analysis is a problem for future study.*

*January 9, 1927. During the course of this study the observation was made, and commented upon frequently, that together with the destruction of the rootlets the nodules were also destroyed. The possible significance of this phenomenon, altho recognized in a general way, was not given careful consideration during this study or during the preparation of this manuscript. Studies on the frenching of tobacco (W. D. Valleau and E. M. Johnson, Science LXIV, 278-279, 1926) have shown that this disease is apparently a nitrogen deficiency trouble. Therefore nitrogen starvation may evidence itself in other ways than the easily recognized yellowing and dying of the lower leaves or general chlorosis. Consideration of these results in connection with the clover failure problem have suggested that nitrogen starvation may play an important part in this problem, also.

The legumes as a group are heavy feeders upon nitrogen when they are growing properly. They may obtain a part of the nitrogen from the soil and the remainder thru nodules. With a thick stand of clover in a grain crop obviously there would be competition for nitrogen, with the grain crop in the best position to obtain it. Figure 8 shows the condition of the root systems of clover seedlings as they generally develop in cultivated soil and figures 9, 10 and 11 show the condition in older plants. It must be evident that many nodules on such root systems are short lived and of comparatively slight value as a source of nitrogen to the plant. Under these conditions may it not be assumed that the first effect of root injury on the nutrition of the clover plant is to limit the amount of nitrogen which it can obtain? Thus the plant is able to develop a top and root system only in proportion to the nitrogen supply. On the more fertile soils nitrogen is present in larger quantities and the plants make a correspondingly larger growth. Nitrogen starvation in legumes has been recognized as a factor where nodule bacteria are not present, in a nitrogen deficient soil, but we believe it is the general view that if nodule bacteria are present, the plant is able to obtain sufficient nitrogen for its needs. Even on the untreated Berea soil, nodules could always be found (Fig. 11) indicating that lack of inoculation, even on the poorest soil under consideration in this study, has not been a limiting factor.

CONCLUSION

It therefore appears safe to conclude that clover failure results indirectly from unfavorable nutritional environment and probably directly as the result of the attack of pathogenic organisms upon the roots, the direct causes being able to operate as the result of, and in direct proportion to, the sub-tone of the plant resulting from the indirect causes.

Among these possible indirect soil causes appear low or unbalanced fertility, unfavorable hydrogen ion concentration, and poor aeration. Since most of the clover mortality is coincident with root loss, which is most severe during the higher temperatures of summer, it appears that such temperature constitutes another unfavorable environmental factor. It seems not unlikely that the droughts during midsummer furnish another factor which contributes to malnutrition of the crop.

It therefore appears reasonable that the general conclusion must be that clover failures, such as are experienced in Kentucky and probably in eastern United States, result from unfavorable nutrition in which soil infertility, unfavorable temperature, and droughty soil conditions are contributing causes, such conditions developing a plant which is seriously injured by pathogenic root organisms, thus greatly reducing the absorbing area of the plant, causing its early death.

Appropriate soil treatment will do much to alleviate the situation responsible for those clover failures which are indirectly or directly due to soil conditions. The development of adapted strains also appears as a very promising possible aid in the solution of clover failures.

Finally the authors venture the prediction, on the basis of observations made during this study, that other deep-feeding crop plants, especially among the legumes, will, as they become longer cultivated, develop failures similar to those which have attended red cover culture.

GENERAL SUMMARY

It is believed that in addition to summary statements previously given, the data presented in this paper justify the following statements:

1. Widespread cultivation of red clover over many years has been followed by difficulties in maintaining the stand for the plants' natural life period.

2. Practically always such difficulties either are due to attacks of extremely pathogenic organisms which kill the plant, irrespective of soil environment, or are correlated with unfavorable soil environment resulting from a depletion of available nutritive elements.

3. Clover failures associated with reduced soil productivity are much more widespread than failures due to other causes.

4. The disappearance of red clover stands on soils where clover fails in Kentucky usually may be correlated with a rotting away of the root systems.

5. Fungi which are injurious to red clover seedlings can be isolated from rotting red clover roots.

6. Root rot of red clover apparently is universal in regions where the plant has been long cultivated. It becomes a critical factor only when environmental conditions are unfavorable to the continuous growth of the plant.

7. Individual plants seem to show resistance to cortical rot of the larger roots.

8. The application of lime, manures and fertilizers to soils on which clover fails regularly decreases the mortality rate of the plant. Such applications do not, however, materially increase root development in unfavorable subsoils.

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